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INSTRUCTION MANUAL

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BOP

BIPOLAR OPERATIONAL

POWER SUPPLY

POWER SUPPLY

Model BOP 72–5 (M)

Serial No. E81591

INSTRUCTION MANUAL

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INSTRUCTION MANUAL CORRECTION

Please note the following corrections to the manual material as indicated:

Parts List and Schematic Diagram:

1. CHANGE:	R401	Resistor, Fixed, Power, Axial	5 ohm, 3W, 5%	Kepco# 115-0700 to:
	R401	Resistor, Fixed, Power, Axial	4 ohm, 3W, 5%	Kepco# 115-1811.
2. CHANGE:	R403	Resistor, Fixed, Power, Axial	30 ohm, 3W, 5%	Kepco# 115-0773 to:
	R403	Resistor, Fixed, Power, Axial	20 ohm, 3W, 5%	Kepco# 115-0851.
3. CHANGE:	R801	Resistor, Fixed, Power, Axial	5 ohm, 3W, 5%	Kepco# 115-0700 to:
	R801	Resistor, Fixed, Power, Axial	4 ohm, 3W, 5%	Kepco# 115-1811.
4. CHANGE:	R803	Resistor, Fixed, Power, Axial	30 ohm, 3W, 5%	Kepco# 115-0773 to:
	R803	Resistor, Fixed, Power, Axial	20 ohm, 3W, 5%	Kepco# 115-0851.

BOP 72-5M/1-2472/r7 BMC

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INSTRUCTION MANUAL CORRECTION

Please note the following corrections to the manual material as indicated:

Parts List and Schematic Diagram:

27.	CHANGE:	Q507 through Q512	Transistor,Silicon,PNP		Kepco No. 119-0090 to:
		Q507 through Q512	Transistor,Silicon,PNP		Kepco No. 119-0107.
28.	CHANGE:	Q907 through Q912	Transistor,Silicon,PNP		Kepco No. 119-0090 to:
		Q907 through Q912	Transistor,Silicon,PNP		Kepco No. 119-0107.
29.	ADD:	CR401,CR402, CR801,CR802	Rectifier,Silicon,Pigtail (See FIG. 4 on page 2 of 3 for location).		Kepco No. 124-0028.
30.	CHANGE:	C401	Capacitor,Ceramic,Disc	200 pF, 6 K V	Kepco No. 117-0075 to:
		C401	Capacitor,Ceramic,Disc	200 pF, 1 K V	Kepco No. 117-0571.
31.	CHANGE:	C801	Capacitor,Ceramic,Disc	200 pF, 6 K V	Kepco No. 117-0075 to:
		C801	Capacitor,Ceramic,Disc	200 pF, 1 K V	Kepco No. 117-0571.

BOP 72–5M/5-770/r1	BMC
BOP 72–5M/7-1470/r2	C2425
BOP 72–5M/10-3070/r3	C2476
BOP 72–5M/7-2470/r4	C2436
BOP 72–5M/9-2371/r5	C2737
BOP 72–5M/10-2271/r6	C2761
BOP 72–5M/12-2871/r7	C2783
BOP 72–5M/4-2672/r7	C2905

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Parts List, Schemtaic and Component Location Diagram (A10):

Protective diodes have been added parallel to the error sensing capacitors:

1) Two (2) diodes (CR1003 and CR1004) have been added parallel (with opposing polarities) to C1002.

18.	CHANGE:	R30	Resistor,Fixed,Precision,M.F.	301 ohm, 1 W, 1%	Kepco No. 115-2066 to:
		R30	Resistor,Fixed,Precision,M.F.	182 ohm, 1 W, 1%	Kepco No. 115-2191.
19.	CHANGE:	CR8,9,13	Silicon,Rectifier,Pigtail		Kepco No. 124-0178 to:
		CR8,9,13	Silicon,Rectifier,Pigtail		Kepco No. 124-0435.
20.	CHANGE:	CR307	Silicon,Rectifier,Pigtail		Kepco No. 124-0178 to:
		CR307	Silicon,Rectifier,Pigtail		Kepco No. 124-0435.
21.	DELETE:	C1003	Capacitor,Electrolytic,Pigtail	150 μF, 3V	Kepco No. 117-0757.
22.	CHANGE:	CR605,606	Silicon,Rectifier,Pigtail		Kepco No. 124-0178 to:
		CR605,606	Silicon,Rectifier,Pigtail		Kepco No. 124-0435.
23.	CHANGE:	CR707	Silicon,Rectifier,Pigtail		Kepco No. 124-0178 to:
		CR707	Silicon,Rectifier,Pigtail		Kepco No. 124-0435.
24.	CHANGE:	T202	Transformer		Kepco No. 100-1880 to:
		T202	Transformer		Kepco No. 100-1965.
25.	CHANGE:	T203	Transformer		Kepco No. 100-1881 to:
		T203	Transformer		Kepco No. 100-1966.
26.	ADD:	F401	Fuse,Instantaneous,3/8A		Kepco No. 141-0076.
		F801	Fuse,Instantaneous,3/8A		Kepco No. 141-0076.

NOTE: The component location of the "Offset Adjust" Assembly (FIG. 6-2, A10 – Detail "G") has been modified and is shown in the FIG. 1 below.

Two fuses have been added for additional pass transistor protection. They are located on the printed circuit boards which are part of the heat sink assemblies (A4, A10). Their location is shown in FIG's 2 and 3 below. Electrical location of both fuses is shown in FIG. 4.

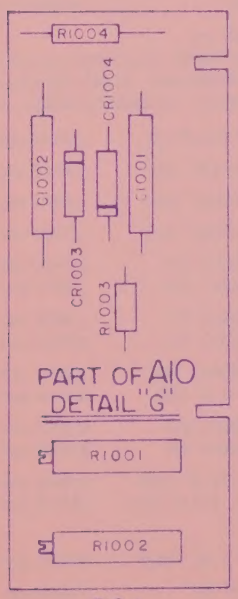

FIG. 1

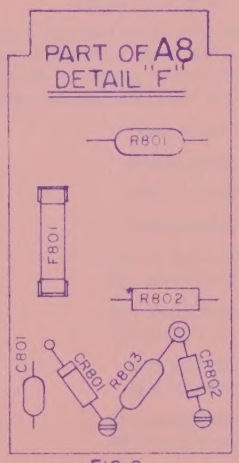

FIG. 2

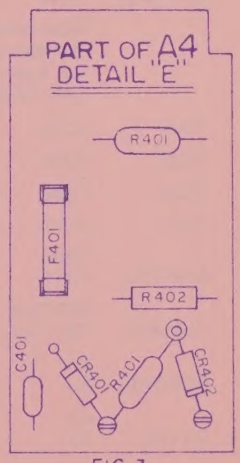

FIG 3

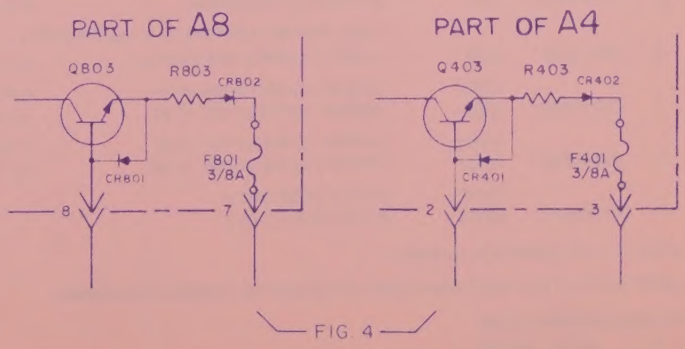

FIG. 4

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INSTRUCTION MANUAL CORRECTION

Please note the following corrections to the manual material as indicated:

Parts List and Schematic Diagram:

1.	CHANGE:	S102	Switch,Slide,DPDT		Kepco No. 127-0279 to:
		S102	Switch,Slide,DPDT		Kepco No. 127-0282.
2.	CHANGE:	R401	Resistor,Fixed,Power,Axial	10 ohm, 3 W, 10%	Kepco No. 115-1181 to:
		R401	Rsistor,Fixed,Power,Axial	5 ohm, 3 W, 5%	Kepco No. 115-0700.
3.	CHANGE:	R801	Resistor,Fixed,Power,Axial	10 ohm, 3 W, 10%	Kepco No. 115-1181 to:
		R801	Resistor,Fixed,Power,Axial	5 ohm, 3 W, 5%	Kepco No. 115-0700.
4.	DELETE:	R39	Resistor,Fixed,Precision,M.F.	71 K ohm, 1 W, 1/2%	Kepco No. 115-2477.
			(R39 has been replaced by a wire jumper.)		
5.	CHANGE:	R31	Resistor,Fixed,Molded	6.2 K ohm, 1/2 W, 5%	Kepco No. 115-0744 to:
		R31	Resistor,Fixed,Molded	1 K ohm, 1/4 W, 10%	Kepco No. 115-2238.
6.	CHANGE:	C5	Capacitor,Mica,Silver Dip	150 pF, 500V, 5%	Kepco No. 117-0675 to:
		C5	Capacitor,Mica,Silver Dip	100 pF, 500V, 5%	Kepco No. 117-0673.
7.	CHANGE:	C7	Capacitor,Ceramic,Disc.	330 pF, 1 K V, 20%	Kepco No. 117-0556 to:
		C7	Capacitor,Ceramic,Disc.	0.05 μF, 500V, 20%	Kepco No. 117-0163.
8.	CHANGE:	C601,602	Capacitor,Mica,Silver Dip	150 pF, 500V, 5%	Kepco No. 117-0675 to:
		C601,602	Capacitor,Mica,Silver Dip	200 pF, 500V, 5%	Kepco No. 117-0783.
9.	CHANGE:	C604	Capacitor,Mica,Silver Dip	100 pF, 500V, 5%	Kepco No. 117-0673 to:
		C604	Capacitor,Mica,Silver Dip	200 pF, 500V, 5%	Kepco No. 117-0783.
10.	ADD:	C308	Capacitor,Mylar,Pigtail	2200 pF, 200V, 10%	Kepco No. 117-0659.
11.	ADD:	C708	Capacitor,Mylar,Pigtail	0.01 μF, 200V, 20%	Kepco No. 117-0353.
12.	ADD:	C309	Capacitor,Mylar,Pigtail	0.05 μF, 500V, 20%	Kepco No. 117-0163.
13.	ADD:	R310	Resistor,Fixed,Molded	200 ohm, 1/2 W, 5%	Kepco No. 115-0538.

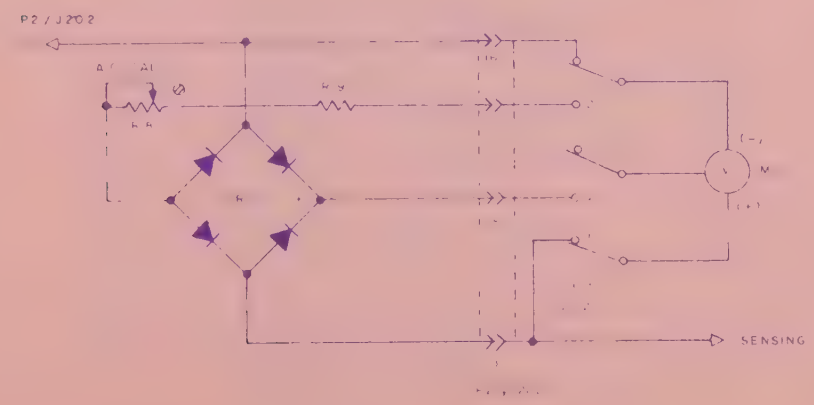
Two capacitors (C308,708) have been added to assemblies A3 and A7, connected parallel to the series resistor combinations R306,308 and R706,708, respectively. A lag network, consisting of a resistor (R310) and a capacitor (C309), has been added. R310 and C309 are series-connected from the base to the collector of Q302, assembly A3.

14.	DELETE:	C306	Capacitor,Electrolytic,Pigtail	10 μF, 6V	Kepco No. 117-0678.
15.	CHANGE:	R16	Resistor,Fixed,Power,Axial	2.5 ohm, 1 W, 5%	Kepco No. 115-1307 to:
		R16	Resistor,Fixed,Precision,M.F.	3.01 K ohm, 1 W, 1%	Kepco No. 115-1852.
16.	CHANGE:	R201	Resistor,Fixed,Power,Strip	200 ohm, 20 W, 5%	Kepco No. 115-0570 to:
		R201	Resistor,Fixed,Power,Strip	150 ohm, 20 W, 5%	Kepco No. 115-0577.

ERRATA:

Please note the following corrections for the text on pages:

6-27/6-28 FIG. 6-4. The metering circuit has been altered as shown below:



17.	ADD:	CR1003,1004	Rectifier,Silicon,Pigtail		Kepco No. 124-0178.

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SECTION I — INTRODUCTION

1-1 SCOPE OF MANUAL

1-2 This manual contains instructions for the installation, operation and maintenance of the Kepco BOP 72 Series of Bipolar Operational Power Supplies.

1-3 INTRODUCTION

1-4 The Kepco BOP 72 Series consists of the models listed in Table 1-1 below. All models are similar in their design, appearance and specifications except as described below:

a) Output ratings as listed in Table 1-1.

b) Models bearing the suffix "M" have operational front panels equipped with output metering, input/output binding post terminals and built-in rheostats for the control of gain and d-c reference potential.

c) Models without suffix have blank front panels except for the a-c circuit breaker, a-c pilot light and openings for offset control adjustments.

1-5 A rear barrier-strip providing for all input/output connections, the recessed offset controls, all other internal adjustments and the a-c circuit breaker and pilot light are common to all models.

MODEL	D-C OUTPUT RANGE		CURRENT SINK	A-C INPUT CURRENT @ 125V A-C
	VOLTS	AMPS		
BOP 72–5M	−72 to +72	−5 to +5	±1A	8.5A
BOP 72–5	−72 to +72	−5 to +5	±1A	8.5A
BOP 72–1.5M	−72 to +72	−1.5 to +1.5	±0.3A	3A
BOP 72–1.5	−72 to +72	−1.5 to +1.5	±0.3A	3A

TABLE 1-1 A-C INPUT/D-C OUTPUT, BOP 72 SERIES.

1-6 The descriptions, instructions and drawings in this manual, if not clearly identified by a specific model designation, are applicable to all models in the BOP 72 Series.

1-7 DESCRIPTION (Refer to FIGS. 1-1, 1-2.)

1-8 The Kepco Bipolar Operational Power Supply (BOP) is a dual purpose instrument capable of responding to a-c or d-c input signals of either polarity. Bipolar input and output are referred to the "common" terminal. The BOP may be represented as a d-c coupled power amplifier in the inverting configuration, delivering a NEGATIVE output for a POSITIVE input and vice versa.

1-9 The BOP is equipped with internal d-c reference sources, accessible at the rear barrier-strip (and on front panel binding posts on models with suffix "M") which deliver a nominal ±6.2 volts, 0–2 mA. This feature allows continuous d-c output control "through zero" by means of a potentiometer connection between the two reference sources and the NULL junction (built-in and labeled "REF." control in models with suffix "M"). The fixed parts of the amplifier offset voltage and offset current can be nulled by using the provided (recessed from the front panel) controls. Offset nulling is especially important if the BOP is used in precision programming by resistance, control voltages or currents.

1-10 An internal MODE switch in the BOP allows transfer of the instrument to two operating modes. In the SLOW mode, the BOP is unconditionally stable for any feedback (including 100%) and any load reactance. The sinusoidal full power frequency response in this operating mode is 2 kHz. In the FAST mode, the BOP is stable for any feedback (including 100%). Load capacitance should be restricted to 0.001 microfarad. The sinsusoidal full power frequency response in this operating mode is 20 kHz.

1-11 The BOP is rendered completely short-circuit proof by two individually adjustable current limit circuits protecting the NPN and PNP leg of the complementary output stage. The a-c input circuit is protected by a circuit breaker.

1-12 The main chassis of the Model BOP Operational Power Supply/Amplifier is constructed of plated steel. The wraparound cover is perforated steel, plated and painted in a dark gray texture. The front panel material is aluminum, treated and painted light gray (Color 26440 per Fed. Std. 595). The major part of the circuitry is located on plug-in type circuit boards for convenient access.

1-13 SPECIFICATIONS, ELECTRICAL

a) A-C INPUT: 105 to 125V a-c or 210 to 250V a-c (selectable), 50 to 65 Hz, single phase. See Table 1-1 for a-c input current.

b) D-C OUTPUT RANGES: See Table 1-1.

c) D-C OUTPUT IMPEDANCE: Model BOP 72–1.5(M) . . . . . 10×10^{-3} ohms.
Model BOP 72–5(M) . . . . . 3×10^{-3} ohms.
(Add 100 μH equivalent series inductance for higher frequencies.)

d) RIPPLE AND NOISE: <0.01% of maximum output or 3 mV rms whichever is greater.

e) OFFSET VOLTAGE AND CURRENT (E_{io}, I_{io}): Zero adjustments provided, accessible from the front panel. Variations of the offset parameters (ΔE_{io}, ΔI_{io}) are specified in Table 1-2.

SPECIFICATION	VOLTAGE AMPLIFIER OFFSETS		6.2V REFERENCES
	ΔE_{io}	ΔI_{io}	
SOURCE: 105–125 or 210–250V a-c	<0.1 mV	<10 nA	<0.0005%
LOAD: No Load/Full Load	<1.0 mV	<10 nA	N.A.
TIME: 8 Hours (Drift)	<0.1 mV	<50 nA	<0.005%
TEMPERATURE: Per °C (Coefficient)	<0.05 mV	<50 nA	<0.005%

TABLE 1-2 D-C SPECIFICATIONS.

NOTE: E_{io} is the offset voltage and I_{io} the offset current referred to the input of the voltage comparison amplifier. Refer to Section IV (Theory of Operation) for an extensive definition and an error analysis.

f) OPEN LOOP D-C GAIN: >35,000 V/V.
CLOSED LOOP: Models with suffix "M" have built-in input resistor and precision gain control adjustable from zero to 10. With external components, closed loop gain may be set as desired.

g) A-C STABILITY:
1) In "slow" mode (selectable by internal switch) device is unconditionally stable for any gain setting including 100% feedback and for any reactive load.
2) In "fast" mode (selectable by internal switch) device is stable for any gain setting including 100% feedback with capacitive loads up to 0.001 μF.

h) DYNAMICS: See Table 1-3.

SPECIFICATION	MODE	BOP 72–1.5M	BOP 72–5M
SMALL SIGNAL FREQUENCY RESPONSE frequency at which the open loop gain becomes unity	FAST	300 kHz	300 kHz
	SLOW	30 kHz	30 kHz
LARGE SIGNAL FREQUENCY RESPONSE frequency at which the fully modulated, fully loaded output reaches 3% harmonic distortion	FAST	20 kHz	20 kHz
	SLOW	2 kHz	2 kHz
AMPLIFIER SLEWING RATE	FAST	9V/μsec.	9V/μsec.
	SLOW	0.9V/μsec.	0.9V/μsec.
PROGRAMMING TIME CONSTANT input/feedback set for gain=10	FAST	12 μsec.	12 μsec.
	SLOW	150 μsec.	150 μsec.
VOLTAGE RECOVERY TIME CONSTANT for step load current	FAST	50 μsec.	50 μsec.
	SLOW	500 μsec.	500 μsec.
CURRENT RECOVERY TIME CONSTANT for step load voltage	FAST	50 μsec.	50 μsec.
	SLOW	500 μsec.	500 μsec.

TABLE 1-3 DYNAMIC OUTPUT SPECIFICATIONS.

i) COOLING: Forced air cooling by high efficiency, long-life fans.

j) REMOTE ERROR SENSING: Special terminals (available at front panel binding posts on models so equipped) and at the rear barrier-strip, permit the connection of the amplifier common and the feedback resistor directly to the load, thus maintaining a low d-c source resistance at the load terminals. Up to 0.5V d-c voltage drop per load lead (due to load current) can be compensated for by remote sensing.

k) OVERLOAD PROTECTION: Output is continuously protected for both polarities and in both operating modes against short circuits. Output current will limit at 5.5A [Model BOP 72–5(M)] and at 1.65A [Model BOP 72–1.5(M)].

l) AMBIENT OPERATING TEMPERATURE RANGE: −20°C to +65°C.

m) STORAGE TEMPERATURE: −40°C to +65°C.

n) ISOLATION VOLTAGE: ±500V (d-c or a-c peak) maximum may be connected from chassis to either output terminal.

o) INTERNAL REFERENCE SUPPLIES: Precision regulated zener sources of plus (+) and minus (−) 6.2 volts (nominal) are provided internally and terminated at the rear as well as on front panel binding posts (on models so equipped). The zener reference sources are temperature compensated and optimized for stability at a load current of 2 mA.

1-14 SPECIFICATIONS, PHYSICAL

a) METERS (Models with suffix "M" only.):

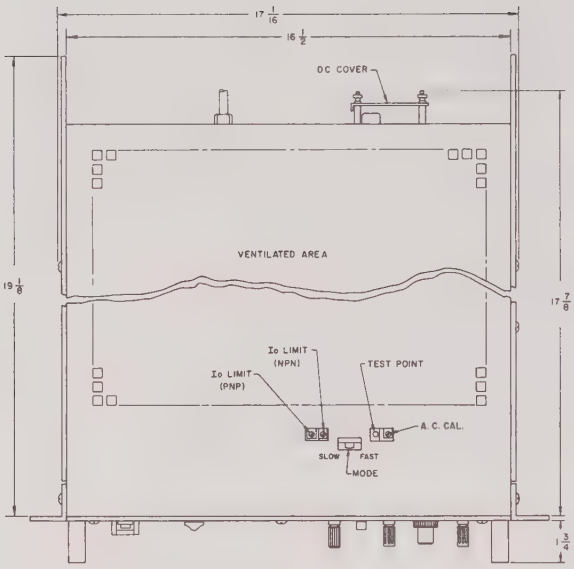
1) Voltmeter, dual purpose moving coil type, ±1% FS, with selector switch to select the ranges: (−)75–0–(+)75 volts (d-c) and 0–75V (rms).

2) Ammeter, moving coil type, ±1% FS, (−)1.5–0–(+)1.5 ampere d-c (Model BOP 72–1.5M) and (−)5–0–(+)5 ampere d-c (Model BOP 72–5M).

b) SIZE AND FINISH: Refer to "Mechanical Outline Drawing" (FIG. 1-3).

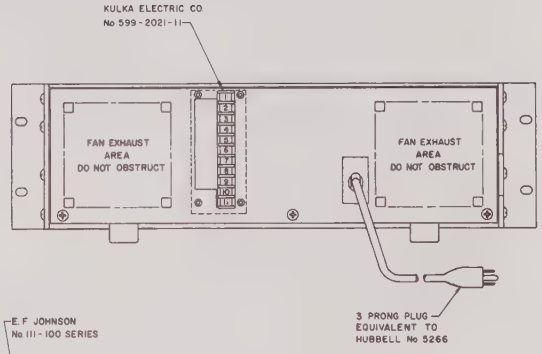
1-15 ACCESSORIES

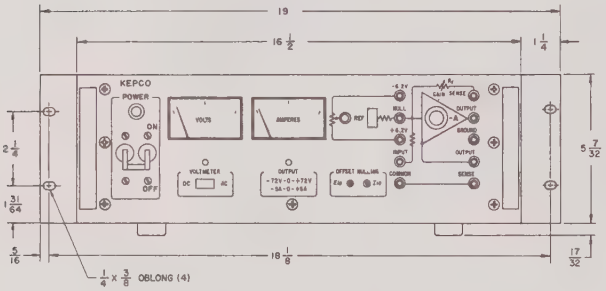
a) Mounting brackets (supplied, refer to FIG. 2-5).

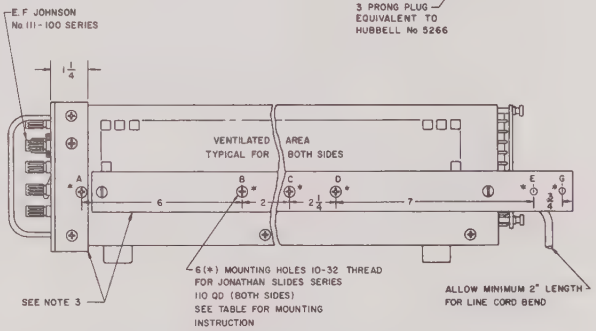


REAR OUTPUT TERMINAL FUNCTIONS

1 SENSING
2 OUTPUT
3 GROUND
4 OUTPUT COMMON
5 SENSING
6 INPUT COMMON
7 INPUT
8 (+) 6.2V (REFERENCE)
9 NULL JUNCTION
10 R_f
11 (-) 6.2V (REFERENCE)


KULKA ELECTRIC CO
No 599-2021-11
FAN EXHAUST AREA DO NOT OBSTRUCT
FAN EXHAUST AREA DO NOT OBSTRUCT
3 PRONG PLUG EQUIVALENT TO HUBBELL No 5266

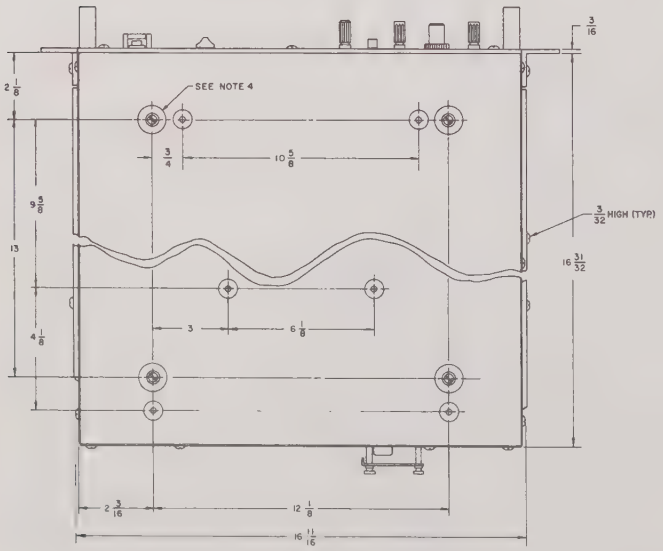




MOUNTING TABLE

SLIDE TYPE	USE MOUNTING HOLES					
	A	B	C	D	E	G
110 QD-20-1	X	X	NOT USED	X	NOT USED	X
110 QD-22-1	X	NOT USED	X	NOT USED	NOT USED	*
110 QD-24-1	X	NOT USED	X	NOT USED	X	NOT USED

* A HOLE HAS TO BE ADDED TO SLIDES # 110 QD-22-1 .199 DIA 18" FROM 'A' HOLE



NOTES

1. MATERIAL: A) CHASSIS: # 11 GA C.R.S.
   B) FRONT PANEL: 3/16 THICK AL
   C) COVER: #16 GA C.R.S.
2. FINISH: A) CHASSIS CADMIUM PLATE WITH A CHROMATE WASH
   B) FRONT PANEL LIGHT GRAY PER FEDERAL STD 595, COLOR # 26440
   C) COVER CHARCOAL GRAY VINYL TEXTURE
3. FIXED ANGLE BRACKETS AND CHASSIS SLIDES SUPPORT BARS (BOTH SIDES) USED FOR RACK OR CABINET INSTALLATION CAN BE REMOVED FOR BENCH OPERATION.
4. (4) ALUMINUM FEET TO BE REMOVED FOR RACK OR CABINET MOUNTING
5. IF INSTALLATION WITHOUT SLIDES IS DESIRED, THE UNIT MUST BE SUPPORTED BY A RIGID PLATFORM, OR BY FIXED BRACKET MOUNTED IN THE RACK SLIDES AND RIGID PLATFORM NOT SUPPLIED

FIG. 1-3 MECHANICAL OUTLINE DRAWING.

SECTION II – INSTALLATION

2-1 UNPACKING AND INSPECTION

2-2 This instrument has been thoroughly tested and inspected prior to packing. After careful unpacking, inspect for shipping damage before attempting operation. Perform the preliminary operational check as outlined in paragraph 2-18 below. If any indication of damage is found, file immediately a claim with the responsible transport service.

2-3 TERMINATIONS AND CONTROLS

a) FRONT PANEL: Refer to FIG. 2-1 and Table 2-1.

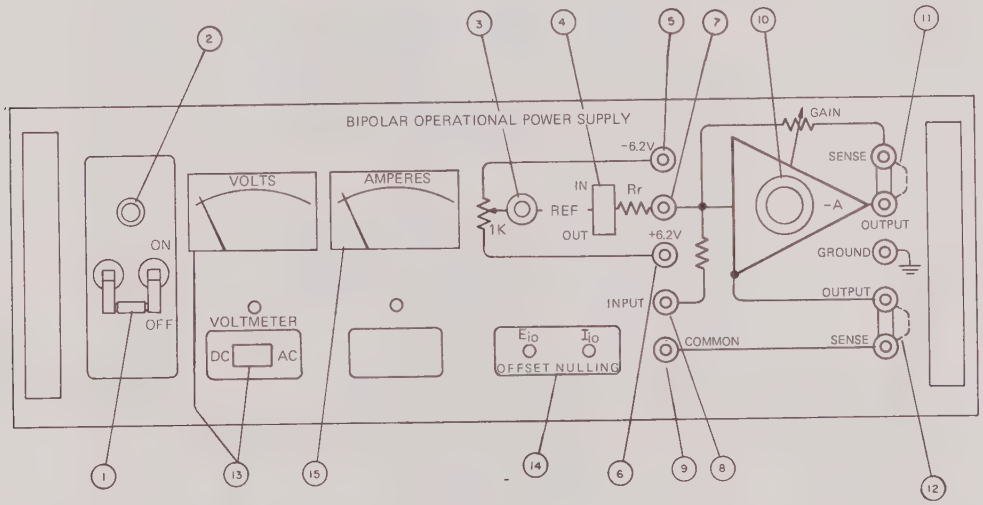


FIG. 2-1 FRONT TERMINALS AND CONTROLS.

NO.	DESCRIPTION OF TERMINATION
1	A-C INPUT POWER SWITCH AND CIRCUIT BREAKER
2	A-C INPUT POWER PILOT LIGHT
3	REFERENCE VOLTAGE CONTROL, ADJUST (–) OR (+) D-C OUTPUT
4	REFERENCE SWITCH. POS. "IN" = ± D-C BIAS AVAILABLE
5	MINUS (–) REFERENCE (–6.2V NOM., REFERRED TO COMMON)
6	PLUS (+) REFERENCE (+6.2V NOM. REFERRED TO COMMON)
7	NULL JUNCTION, INPUT TO (INVERTING) AMPLIFIER
8	INPUT FOR 0–10 GAIN WITH BUILT-IN GAIN CONTROL (R_i = 4 K ohm)
9	COMMON TERMINAL
10	PRECISION SINGLE TURN VOLTAGE CONTROL (POWER SUPPLY) OR GAIN CONTROL (AMP)
11	PLUS (+) OR MINUS (–) OUTPUT AND SENSING. LINKED AT FRONT OR REAR, OR CONNECTED AT THE LOAD (REMOTE SENSING)
12	COMMON OUTPUT AND SENSING. LINKED AT FRONT OR REAR, OR CONNECTED AT THE LOAD (REMOTE SENSING)
13	DUAL PURPOSE METER AND SELECTOR SWITCH. MEASURES D-C OUTPUT VOLTAGE AND A-C OUTPUT VOLTAGE
14	OFFSET NULLING CONTROLS (RECESSED SCREWDRIVER ADJUSTMENTS)
15	OUTPUT CURRENT METER

TABLE 2-1 FRONT TERMINALS AND CONTROLS.

b) REAR: Refer to FIG. 2-2 and Table 2-2.

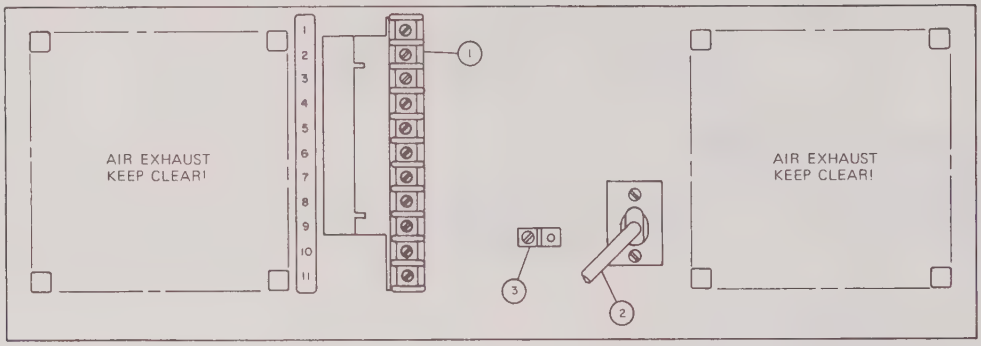


FIG. 2-2 REAR TERMINALS.

NO.		DESCRIPTION OF TERMINATION
1		REAR BARRIER-STRIP (TB1301), TERMINAL FUNCTIONS ARE:
	1	PLUS (+) OR MINUS (–) OUTPUT (2) AND SENSING (1) LINKED AT FRONT*
	2	OR REAR, OR CONNECTED AT THE LOAD (REMOTE SENSING)
	3	CHASSIS CONNECTION; RETURN TO A-C GROUND
	4	COMMON OUTPUT (4) AND SENSING (5), LINKED AT FRONT* OR
	5	CONNECTED AT THE LOAD (REMOTE SENSING)
	6	INPUT COMMON, LINK-CONNECTED TO SENSING COMMON (5)
	7	INPUT FOR 0–10 GAIN WITH BUILT-IN GAIN CONTROL (R_i = 4 K ohm)
	8	PLUS (+) REFERENCE (+6.2V NOM., REFERRED TO COMMON)
	9	NULL JUNCTION. INPUT TO (INVERTING) AMPLIFIER
	10	R_f GAIN CONTROL LINKED TO NULL (9)
	11	MINUS (–) REFERENCE (–6.2V NOM., REFERRED TO COMMON)
2		A-C POWER INPUT CORD* OR INPUT REAR BARRIER-STRIP
3		SPARE SHORTING LINKS*

*Models with suffix "M" only.

TABLE 2-2 REAR TERMINALS.

c) INTERNAL ADJUSTMENTS: Refer to FIG. 2-3 and Table 2-3.

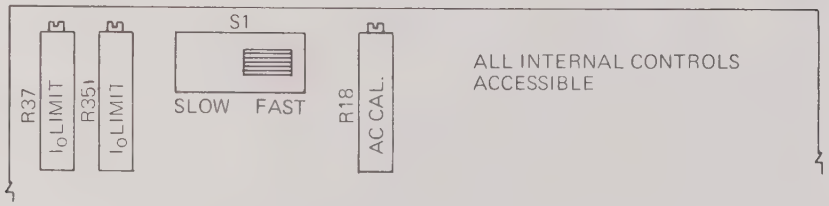


FIG. 2-3 LOCATION OF INTERNAL CONTROLS.

REFERENCE DESIGNATION	ADJUSTMENT	PURPOSE	ADJUSTMENT PROCEDURE
R18**	A-C Meter Cal.	A-C Meter Scale Calibration	Par. 5-7
R35	I_o Limit (NPN)	Output Current Limit Adjustment	Par. 5-7
R37	I_o Limit (PNP)	Output Current Limit Adjustment	Par. 5-7
R1001	E_{io} Null*	Offset Voltage Zero Adjustment	Par. 3-15
R1002	I_{io} Null*	Offset Voltage Zero Adjustment	Par. 3-15
S1	Mode Switch	Slow/Fast Operating Mode	

*The Offset Zero Adjustments (E_{io} Null, I_{io} Null) are (recessed) front panel controls.
**This control provided on models with suffix "M" only.

TABLE 2-3 INTERNAL ADJUSTMENTS.

2-4 A-C INPUT SOURCE REQUIREMENTS

2-5 The BOP Power Supply/Amplifier is normally delivered for operation on a single phase, 105 to 125 volts a-c input source, 50 to 65 Hz. For operation on 210 to 250 volts a-c input, the jumper connections on the main transformer (T201) must be changed as described below.

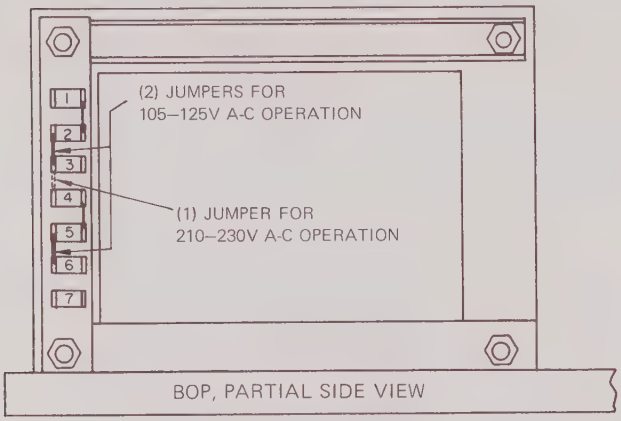


FIG. 2-4 MAIN TRANSFORMER PRIMARY CONNECTIONS.

2-6 PROCEDURE (Refer to FIG. 2-4.)

a) Disconnect the BOP from the a-c input source.
b) Remove cover and rear chassis bracket.
c) Unsolder and remove the bare wire jumpers between transformer terminals (2) – (3) and (5) – (6).
d) Connect and solder new jumper between transformer terminals (3) – (4).

2-7 GROUNDING

WARNING

2-8 A-C SAFETY GROUND. This instrument is either equipped with a three-wire safety line cord and a polarized plug (metered models, suffix "M") or a three-terminal barrier-strip for a-c power input. THE POLARIZED PLUG ON THE METERED MODELS MUST BE CONNECTED TO A GROUNDED A-C POWER OUTLET, AND THE GROUND TERMINAL (G) ON THE UNMETERED MODELS MUST BE RETURNED TO A-C GROUND TO ASSURE OPERATOR SAFETY.

2-9 SIGNAL GROUND. The output of this instrument has no d-c connection to the a-c power source or the chassis. An internal signal ground is provided consisting of a resistor/capacitor combination (R1003, C1001) connected from the COMMON OUTPUT to ground. If an external signal ground is desired, the internal ground may be opened by removing the capacitor from the printed circuit board (A10, see FIG. 6-2 for location).

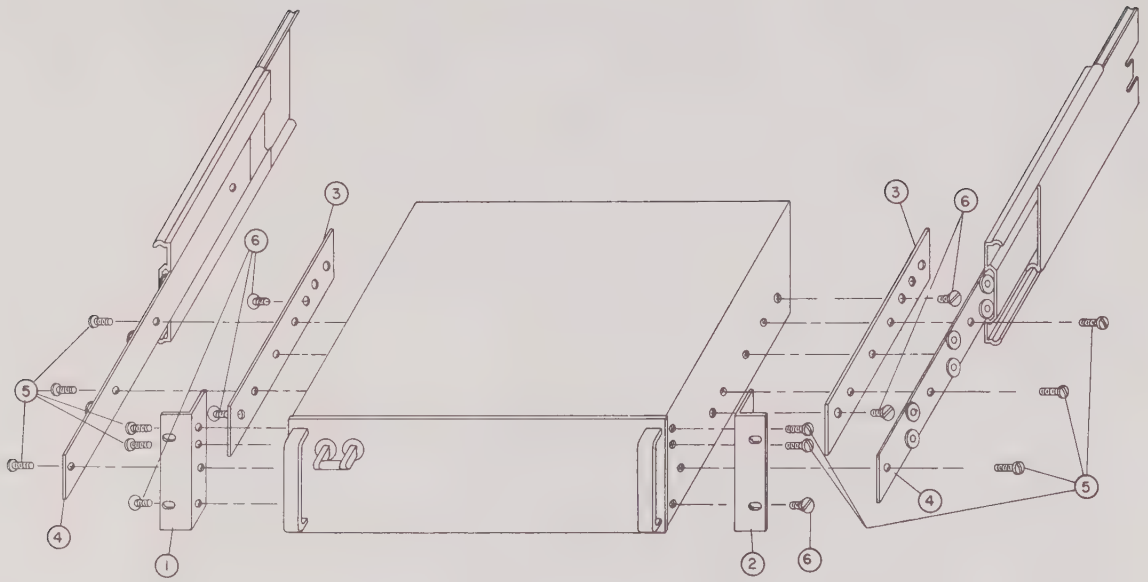
2-10 ISOLATION

2-11 All output and input terminals on the BOP are (d-c) isolated from the a-c power input source and from the chassis. Either output terminal may therefore be grounded or a maximum of 500 volts (d-c or peak) may be connected between the chassis and either output terminal.

2-12 INSTALLATION

2-13 METERED MODELS (SUFFIX "M"). The BOP may be operated as a bench instrument or with the assistance of the provided mounting brackets, it may be installed into any standard 19 inch rack. Please refer to paragraph 2-15 (Cooling) if the instrument is to be mounted into a multiple-unit rack installation. Instructions for rack-mounting are provided. (See FIG. 2-5.)

2-14 UNMETERED MODELS (NO SUFFIX). The unmetered instruments are constructed in modular form for direct chassis mounting into systems installations. For mounting-hole dimensions and layout, see "Mechanical Outline Drawing" (FIG. 1-3). Please refer to paragraph 2-15 if the instrument must be installed into confined spaces.



RACK MOUNTING ACCESSORIES, PARTS LIST		
ITEM	DESCRIPTION	QTY.
1	FRONT ANGLE LEFT	1
2	FRONT ANGLE RIGHT	1
3	FILLER BRACKET	2
4	SLIDES: 110 QD JONATHAN SERIES	2
5	10–32 SCR BDG. HD.	10
6	10–32 FLATHEAD 82°	6

NOTE: ITEM (4) NOT SUPPLIED.

INSTRUCTIONS FOR SLIDE INSTALLATION

1) Items 1, 2, 3 are installed at the factory.
2) Item 3 (filler bracket) is predrilled and tapped for Jonathan Slides, Series 110 QD. Remove the three binding head screws on each side of Item 3. (These screws are part of Item 5.)
3) Line up slide with filler bracket and reinsert the binding head screws through the appropriate mounting holes in the slide.
4) If Jonathan Slide 110 QD–24–1 is used, an additional hole must be drilled into the slide. See FIG. 1-3 for further information.

FIG. 2-5 RACK INSTALLATION, "FULL RACK" MODELS.

NOTE: If slide installation (as described above) is not desired, other means of supporting the unit in the rear must be provided (additional rear brackets or a solid platform, for example) since the front angle brackets (Items 1, 2) alone are not sufficient to support the full weight of the unit.

2-15 COOLING

2-16 The power transistors in the BOP are located on highly efficient heat sinks and cooled by forced air. SIDES, REAR AND TOP OF COVER MUST BE FREE FROM OBSTRUCTIONS SO THAT FREE AIR CIRCULATION IS NOT IMPEDED. Periodic cleaning of the interior of the instrument is recommended. If the instrument is rack mounted or installed into confined spaces, care must be taken that the temperature immediately surrounding the instrument does not rise above the specified limit (+65°C).

2-17 PRELIMINARY ELECTRICAL CHECK

2-18 A simple electrical checkout after unpacking and before permanent installation is advisable to ascertain whether the instrument has suffered damage during shipment. Refer to FIGS. 2-1, 2-2 and Tables 2-1, 2-2 for the identification and location of all controls and terminations. The nomenclature used will be followed throughout this manual. Controls and terminations pertaining to the BOP will be capitalized throughout the text.

a) METERED BOP MODELS (SUFFIX "M")

1) CIRCUIT BREAKER/POWER SWITCH "off." Connect the BOP to the 115V a-c input power source or check paragraph 2-4 for conversion to 230V a-c operation if desired.

2) CIRCUIT BREAKER/POWER SWITCH "on." The red a-c pilot lamp should be energized. With the "REF." switch in the "IN" position and the "REF." control fully clockwise, unlock the GAIN control by turning the rear knob fully counterclockwise. The GAIN control is a high resolution vernier potentiometer connected as a rheostat and acting as a "coarse/fine" gain adjustment. Slowly turn the GAIN control clockwise. Observe the panel VOLTMETER. (SELECTOR SWITCH should be in the d-c position.) The output voltage should vary smoothly from zero to (positive) full scale as the GAIN control is varied through its complete range.

3) Repeat check with the "REF." control counterclockwise. Output voltage should vary from zero to the rated negative value as the GAIN control is turned through its complete range.

4) Check AMPERE METER action by loading the BOP with an appropriate resistor load ($R_L = E_{o\ max.}/I_{o\ max.}$) connected across the OUTPUT terminals. As the GAIN control is varied through its complete range with the "REF." control first fully counterclockwise, then clockwise, the output current should smoothly vary from the rated maximum negative value to the rated maximum positive value. This concludes the preliminary check for metered BOP models.

b) UNMETERED BOP MODELS (NO SUFFIX)

1) CIRCUIT BREAKER/POWER SWITCH "off." Connect a 1 K ohm potentiometer ("REF." control), the external metering and the load to the BOP rear terminals as shown in FIG. 2-6 below. Disconnect ballast resistor R1005 (located on A10, see FIG. 6-2). This resistor is mounted on turret lugs for convenient access. It may be removed completely if an external "REF." control is used permanently.

2) CIRCUIT BREAKER/POWER SWITCH "off." Connect the BOP to the 115V a-c input power source or check paragraph 2-4 for conversion to 230V a-c if desired.

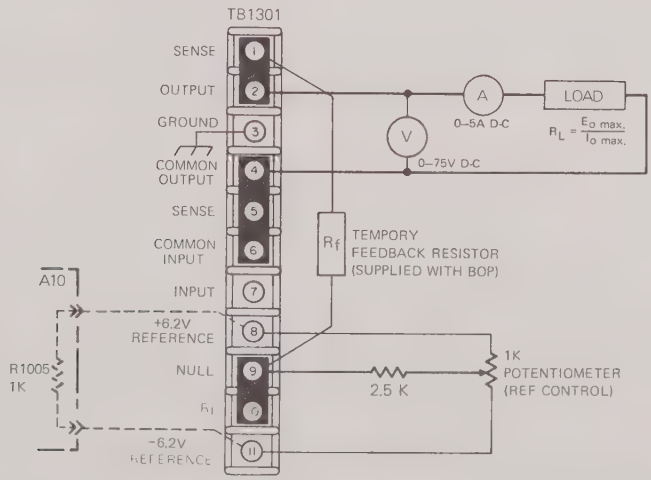


FIG. 2-6 TEST SETUP FOR PRELIMINARY CHECK ON UNMETERED BOP MODELS.

3) CIRCUIT BREAKER/POWER SWITCH "on." Observe output metering while varying the external "REF." control. The output (voltage and current) should vary smoothly from the maximum rated negative values through zero, to the maximum rated positive values as the "REF." control is varied through its complete range. THE METER CONNECTIONS MUST BE REVERSED AS THE BOP OUTPUT CHANGES POLARITY. This concludes the preliminary check for unmetered BOP models.

4) IMPORTANT NOTE:
If output effects due to time (drift) or due to temperature (temperature coefficient) are to be measured, the temporary feedback resistor (supplied and mounted across rear terminals) and the external "REF." potentiometer must be replaced by high quality components having temperature coefficients of 20 parts per million or less.

5) An alternate method of output control may be performed by replacing the fixed (supplied, mounted on rear terminals) feedback resistor by a variable GAIN control while the "REF." control potentiometer is left at a fixed position. The external GAIN control (40 K ohm potentiometer connected as a rheostat) is connected in place of the fixed feedback resistor between rear terminals (1) and (9). The external GAIN control will now control the output from zero to a value given by the position of the "REF." control. If the wiper "REF." control potentiometer is set completely towards the positive reference voltage (+6.2V, terminal 8), the maximum output will be the rated negative value, for example.

NOTE: This Bipolar Operational Supply is equipped with a two-second time delay relay, designed to prevent immediate turn-on after the a-c power is interrupted. The purpose of the delay is to permit the main filter capacitors sufficient time for discharge before the reapplication of a-c power. If the turn-on should appear hesitant or the switching "noisy," it may be due to the relay cycle which is a normal condition. Refer to paragraph 4-51 (Overshoot Protection Circuit) for a detailed description of the relay circuit.

SECTION III – OPERATION

3-1 D-C OUTPUT, LOCAL CONTROL

3-2 GENERAL. Kepco Bipolar Operational Power Supplies (BOP) can be locally controlled either by means of built-in front panel controls (models with suffix "M" only) or with external controls connected to the rear barrier-strip (all models). Two basic methods of locally controlling the d-c output voltage have been briefly described in the previous section. (See "Preliminary Electrical Check," par. 2-17.) These two methods may be used separately or combined. If the "REF." control is set either fully clockwise or counterclockwise (by means of the internal or external potentiometer), a negative or positive control current (I_b) of approximately 2 mA is produced:

$$E_r/R_r = I_b \text{ or } 6V/3\ K \approx 2\ mA \qquad \text{(Eq. 1)}$$

The output voltage can now be linearly controlled by means of the built-in GAIN control (models with suffix "M") or the externally connected feedback resistor (R_f) if the latter is changed to a rheostat. The (simplified) transfer function governing this method of control can be expressed by:

$$E_o = (E_r/R_r)\ R_f \qquad \text{(Eq. 2)}$$

Combining equations (1) and (2), we have:

$$E_o = I_b(R_f) \qquad \text{(Eq. 3) where:}$$

E_o = Output Voltage
E_r = Reference Voltage
R_f = Gain Control (Feedback Resistor)
R_r = Reference Resistor
I_b = Control Current

3-3 Referring to Eq. 3, both control methods become obvious. With I_b a fixed 2 mA, the output voltage becomes a linear function of the internal or external setting of the GAIN control (R_f). Alternately, if the GAIN control is left in any fixed position and the "REF." control is varied, the output voltage becomes a function of the control current I_b. The control current is determined by the setting of the "REF." control which is connected between the ± 6.2 volt reference voltages. Since the reference resistor (R_r) is connected in series with the wiper of the "REF." potentiometer, the control current (I_b) can be selected between the values of − 2 mA and + 2 mA. Output voltage control from the maximum rated negative to the maximum rated postive value (continuous through zero) is therefore possible with this method. If, for example, a BOP 72–5 is to be controlled as described above, the output voltage at any setting can be expressed by:

$$\pm E_o = \pm E_r \left[\frac{R_f}{R_r}\right], \text{ or:}$$

$$\pm 72V \approx \pm (0 \text{ to } 6V)\ \left[\frac{0 \text{ to } 40\ K \text{ ohms}}{3\ K \text{ ohms}}\right]$$

3-4 While output voltage control by means of the GAIN control is linear from zero to either a negative or positive end value (depending upon the polarity of the control current), continuous control, through zero, by means of the "REF." control is inherently somewhat nonlinear (≈20%) due to the flow of current through the potentiometer ("REF." control).

3-5 LOAD CONNECTION. BOP models with functional front panels (models with suffix "M") have the links between output and error sensing terminals connected at the front panel binding posts. (See FIG. 3-1.) A pair of "spare links" are provided for these models at the rear (See FIG. 3-2) for the case where the load is to be connected at the rear. In the latter case, the front links must be removed and the rear links connected as shown. BOP models without functional front panel (no suffix) have the links connected at the rear as shown. (See FIG. 3-2)

3-6 The load may be connected to the output terminals at the rear barrier strip or at the front panel binding posts. (See FIGS. 3-1, 3-3, 3-4.) Load wires should be of the largest practicable diameter to reduce voltage drops due to load current and to keep the output impedance as low as possible. If specified regulation directly at the load is required, remote error sensing must be used as described below.

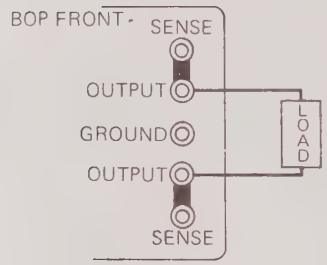


FIG. 3-1 LOAD CONNECTION, FRONT PANEL
(without error sensing).

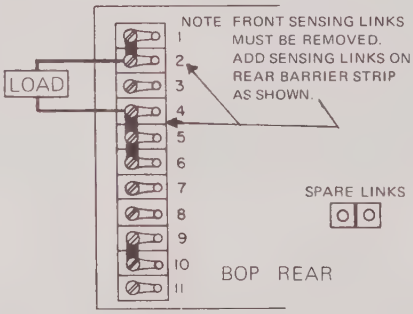


FIG. 3-2 LOAD CONNECTION, REAR
(without error sensing).

3-7 **REMOTE ERROR SENSING.** For applications requiring specified d-c performance directly at the load, remote error sensing may be used to compensate for voltage drops along the load connecting wires. Up to 0.5V per load lead can be corrected. Error sensing may be used either from the front binding posts or at the rear barrier-strip. In the latter case, the front links between output and sensing terminals must be removed. (Refer to FIGS. 3-3, 3-4.)

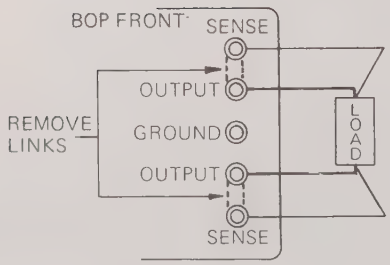


FIG. 3-3 LOAD CONNECTION, FRONT PANEL
(with error sensing).

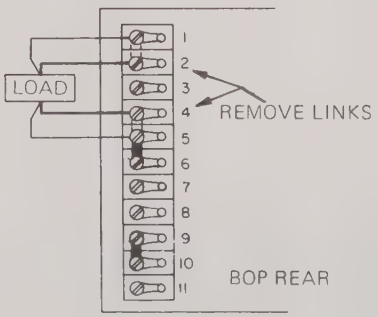


FIG. 3-4 LOAD CONNECTION, REAR
(with error sensing).

3-8 INTRODUCTION TO REMOTE PROGRAMMING

3-9 GENERAL. The following paragraphs contain a sampling of possible applications of the BOP Operational Power Supply/Amplifier. The scope of this manual allows for the discussion of only a few of the almost unlimited number of operational circuits. The reader is referred to Section IV (Theory of Operation) for a short review of operational theory and to the available literature on operational amplifiers. For an extended treatment of power supply programming, please refer to the "Kepco Power Supply Handbook," available from your Kepco Representative or directly from:

KEPCO, INC.
131-38 Sanford Ave.
Flushing, New York 11352

3-10 DIAGRAMS. The operating and test setup diagrams in this section represent ALL BOP models. The diagrams are simplified, symbolic illustrations of the BOP Operational Power Supply. Encircled, numbered terminals are rear barrier-strip connections (part of ALL BOP models) while the nomenclature on all terminals coincides with the front panel labeling on those models which carry the suffix "M." The GAIN control, the "REF." switch, the "REF." control and the reference resistor (R_r = 3 K ohm), although shown in all diagrams, are only part of the models with functional front panels (suffix "M"). These components can be added on models without functional front panel (without suffix "M") if the applications so require.

3-11 GROUNDING. Excessive ripple (line frequency "pickup") at the output is often due to improper or multiple grounding (ground loop). All remote programming or amplifier systems must have a single ground point only to which all shields, equipment cases and the COMMON input/output lead should be connected. (See also pars. 2-7 and 2-9.)

3-12 EXTERNAL PROGRAMMING COMPONENTS

a) RESISTORS. Resistors for external programming should be high quality, wirewound units with temperature coefficients of 20 parts per million or better. Their wattage rating should be at least 10 times the quiescent power dissipation. (Although the control current flowing through these resistors is normally quite low, large energy peaks may occur when programming voltage step functions.)

b) INPUT SOURCES. External programming sources should have stability specifications equal to or better than the BOP.

c) EXTERNAL SWITCHES. If step switch devices are used in resistance programming, they must be of the "make before break" variety to avoid opening the feedback loop.

d) EXTERNAL LEADS. Shielded leads should be used for all external connections, except for load wires, which should be of the heaviest diameter practicable and twisted, to reduce inductance. (Excessive load wire inductance adds to the power supply impedance and may cause deterioration of transient response.) Load capacity, see bandwidth specifications, paragraph 1-13.

3-13 PRELIMINARY ADJUSTMENTS

3-14 The initial offsets (E_{io}, I_{io}) of the amplifier are carefully zeroed at the factory at 25°C and after 30 minute warmup. Built-in trim rheostats accesible through front panel openings and appropriately labeled are provided for readjustment after component replacement or at other operating temperatures. For applications requiring high programming accuracy, the procedures described below should always precede actual operation.

3-15 PROCEDURE, OFFSET ZEROING

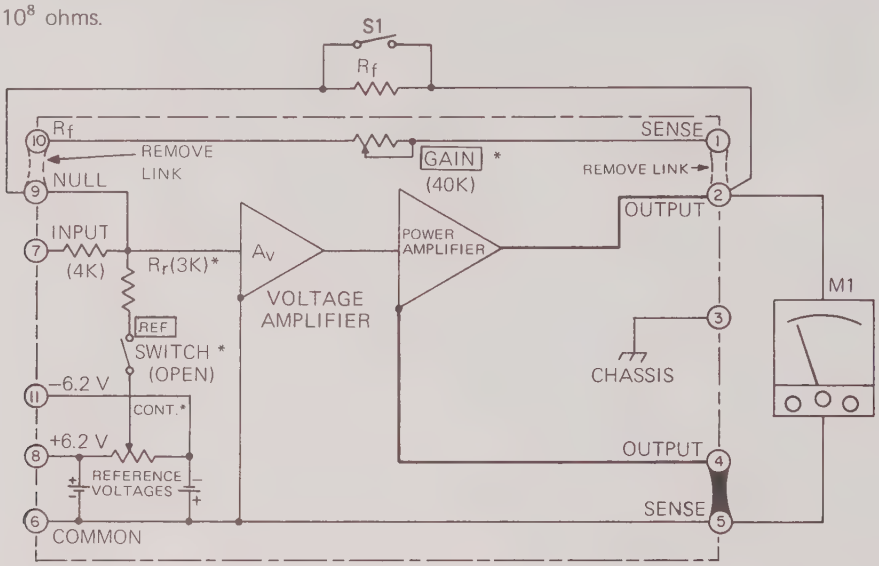
a) EQUIPMENT REQUIRED:

1) Sensitive Null Detector, MILLIVAC MODEL MV-07A or equivalent, or oscilliscope, TEKTRONIX MODEL 502 A (M1).
2) Switch, SPST (S1).
3) Resistance Decade Box (megohm range) or single resistor (R_f).

b) OFFSET VOLTAGE ZERO ADJUST (Refer to FIG. 3-5):
Close S1. Locate OFFSET VOLTAGE NULLING adjustment (marked E_{io}) at the front panel. Adjust control until null detector (M1) reads precisely zero. The adjustment may shift slightly as the BOP amplifier (and the null detector) reach thermal equilibrium. Repeat adjustment as necessary.

c) OFFSET CURRENT ZERO ADJUST (Refer to FIG. 3-5):
Open S1. Locate OFFSET CURRENT NULLING ADJUSTMENT (marked I_{io}) and set to exact zero as indicated on M1. Increase sensitivity of adjustment by increasing the resistance (R_f) across the feedback terminals. Repeat adjustment as necessary. With care, the offset current can be reduced to a few

nanoamperes. (One nanoampere across 5 megohms represents an output voltage of 5 mV as read out on M1.) Offset current nulling results in increasing input impedance (looking into the feedback terminals). This becomes important in applications where the BOP is used as an impedance transformer since the feedback terminals represent the input of the circuit. Impedance in this case will be directly proportional to the residual effect of the offset current. With careful adjustment, Z_{in} can be raised to $10^7 - 10^8$ ohms.



NOTE: 1) ENCLOSED NUMBERS ARE REAR BARRIER STRIP TERMINAL DESIGNATIONS.
2) COMPONENTS MARKED WITH "*" ON MODELS WITH SUFFIX "M" ONLY. ADD EXTERNALLY, IF APPLICATION REQUIRES.

FIG. 3-5 TEST SET-UP FOR OFFSET ZEROING

FIG. 3-5 TEST SETUP FOR OFFSET NULLING.

3-16 REMOTE RESISTANCE PROGRAMMING

3-17 The output voltage of the BOP may be controlled remotely by means of an external feedback resistance connected between the appropriate front or rear terminals. The external feedback resistance may be fixed, continuously adjustable or step-controlled or it may be a combination of these. Its high speed characteristics and specifications make the BOP especially suitable for high speed remote control where the external feedback resistance is changed by means of relays or solid state switching arrangements.

3-18 The value of the feedback resistance for any given output voltage is given by the transfer function:

$$E_o = I_b R_f, \quad \text{where:}$$

E_o = Desired Output Voltage
I_b = Control Current
R_f = Feedback Resistance

If the internal reference sources are used ("REF." switch in position "in"), I_b becomes a function of the position of the "REF." control. I_b may be made any value between −2 mA and +2 mA, depending on the position of the "REF." control. If, for example, we desire a zero to −60V output swing on a Model BOP 72–5(M), the "REF." control would be set to −2 mA (extreme counterclockwise position) and R_f calculated by:

$$E_o = I_b R_f, \text{ or: } -60V = (-2\ mA)\ R_f,$$

$$(R_f) = 30\ K\ ohms.$$

Resistor tolerances may be corrected by adjusting the "REF." control, until a precision meter at the output shows exactly 60 volts. If, on the other hand, a precision resistor with low tolerance is available for R_f, the output voltage may be adjusted with the "REF." control to exactly 2 mA X (R_f), thus establishing a "programming ratio" of 500 ohms per volt, i.e. for each 500 ohms of feedback resistance, one volt will appear at the output.

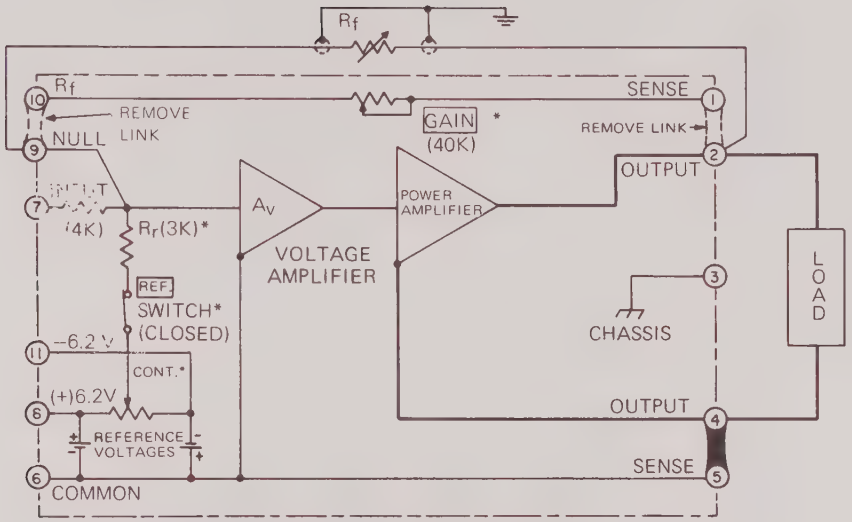


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FIG. 3-6 PROGRAMMING WITH EXTERNAL RESISTANCE.

3-19 PROCEDURE (Refer to FIG. 3-6.)

a) Determine value of programming resistor (R_f) for output voltage desired.

b) Using two-wire, shielded cable, connect R_f to either front or rear terminals as shown. Connect shield to signal ground.

c) The output voltage will vary from (−2 mA) times (R_f minimum) to (−2 mA) times (R_f maximum) as the feedback resistor value is changed between its limits.

NOTE: Transfer internal bandwidth switch to the SLOW position, if overshoot, ringing or instability (oscillation) indicate excessive phase shift caused by the load.

3-20 AMPLIFIER OPERATION, VOLTAGE MODE

3-21 Standard bipolar programming with the BOP Operational Power Supply/Amplifier may be performed without elaborate preparation. Once the amplifier offsets have been adjusted (see par. 3-13), the "REF." switch is transferred to position "out" (if d-c biasing is not needed), and the BOP is ready for operation. Now the required operational gain can be determined and the necessary input and feedback components selected. For the calculations, we make use of the (idealized) operational amplifier equation:

$$E_o = E_i \left[\frac{R_f}{R_i}\right] \qquad \text{(Eq. 2), where:}$$

E_o = Output Voltage
E_i = Input Voltage
E_i = Input Resistor
R_f = Feedback Resistor

The ratio R_i/R_f is the "closed-loop" or "operational" gain of the BOP. If the provided INPUT (R_i = 4 K ohm at rear terminal 7 or at the front panel if BOP is so equipped) in combination with a 40 K ohm GAIN control is used (built-in on models with suffix "M"), the operational gain is variable from zero to 10 (R_f/R_i = 40 K/4 K = 10). Other gain ratios may be selected by calculating the necessary input and feedback components and, using the (direct) NULL input terminal, connecting these components externally.

3-22 Before any application, the gain/frequency properties of the BOP in the amplifier mode should be considered. An idealized graph of this characteristic (Bode plot) is shown in FIG. 3-7 below.

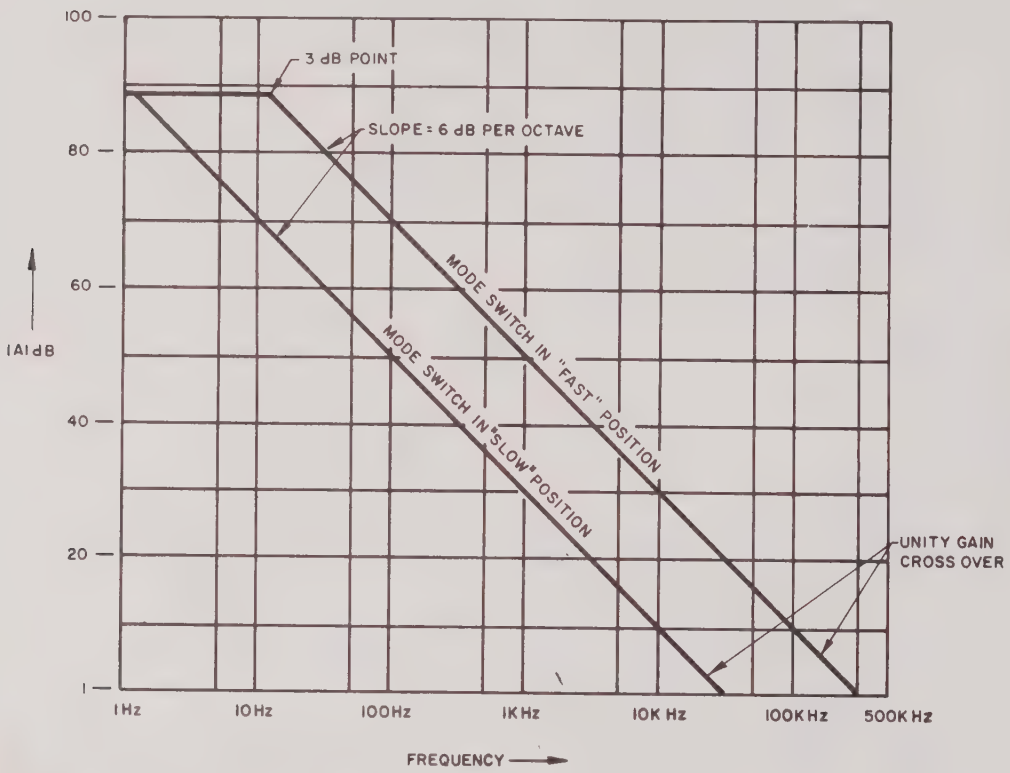

FIG. 3-7 BODE PLOT FOR BOP.

3-23 BIPOLAR INPUT WITH VARIABLE GAIN (Local and Remote Control)

3-24 Example I: A Model BOP 72–5(M) is to be programmed to deliver a 50V p-p sine wave into a resistor load. The input source available is a generator with a maximum output of 5V p-p into 600 ohms. Since a gain of 10 (20 dB) is needed, we can expect maximum frequency response of about 30 kHz with the bandwidth switch in the FAST position. Using the internal GAIN control in combination with the INPUT terminal results in a convenient output control for the amplified sine wave. (Refer to FIG. 3-8.)

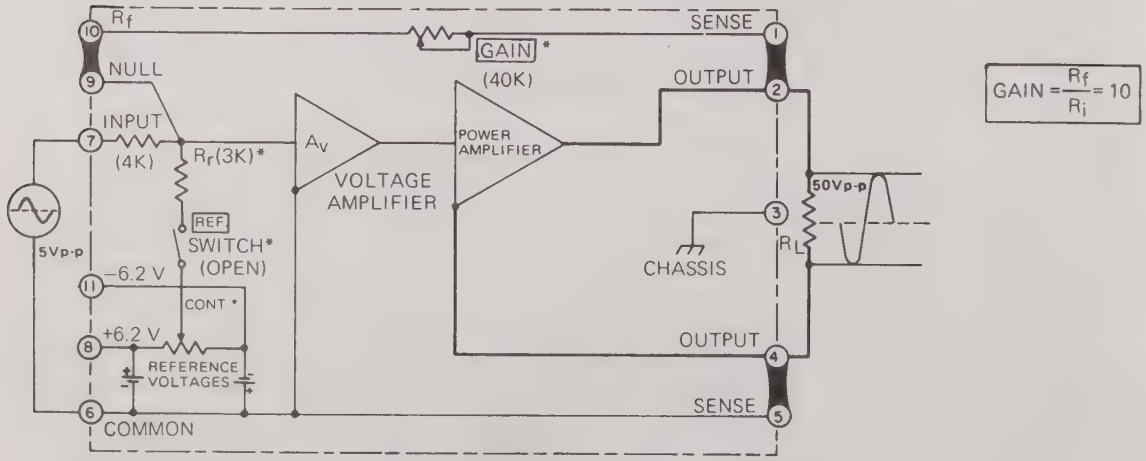

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FIG. 3-8 BIPOLAR INPUT WITH VARIABLE GAIN (LOCAL CONTROL).

3-25 If other gain ratios are desired or the instrument is to be remote controlled, the necessary input and feedback resistors may be readily calculated utilizing Equation 2:

$$E_O = E_i \left[\frac{R_f}{R_i}\right]$$

If, for example, the available input voltage is only 2V p-p, we would need a gain of 25 (28 dB) to produce a 50V p-p output. The value of the input resistor (R_i) will depend upon the source impedance of E_i if, for example:

$$R_{source} = 400 \text{ ohms},$$

R_i' could be chosen 600 ohms, so that

$$R_{source} + R_i' = R_i = 1 \text{ K ohm},$$

then R_f would be calculated by:

$$R_i G = R_f = (1 \text{ K})\ (25) = 25 \text{ K } \Omega$$

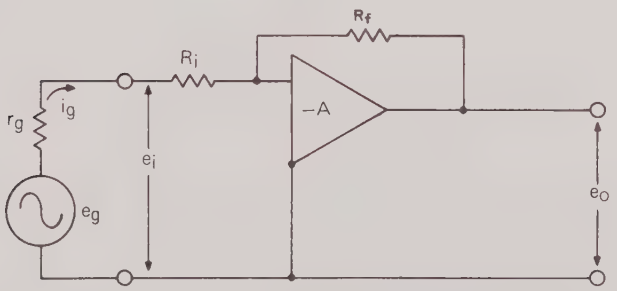
Making R_f a variable resistor will result in convenient control over the required range. (Refer to FIG. 3-9).

3-26 Other input sources such as sawtooth or square-wave voltages may be used to program the BOP if the gain/bandwidth criterium is kept in mind. If the input source has a d-c component which must be blocked, the coupling capacitor must be selected large enough to pass the lowest frequency of interest or:

$$C \geqslant \frac{10}{2\pi f R_i} \qquad X_C \leqslant \frac{R_i}{10}$$

Where R_i is the input resistance, and (f) is the frequency of interest (3 dB point).

NOTE: If the input source has an appreciable source resistance, it must be considered in all gain calculations. Although the equation for the output voltage (2) does not change, we must remember that e_i is not the open circuit output voltage from the generator but the input voltage to the closed-loop system (FIG. 3-9).



$$e_O = e_i \left(\frac{R_f}{R_i}\right)$$

$$e_O = e_g \left(\frac{R_f}{R_i + r_g}\right)$$

FIG. 3-9 INPUT SOURCES WITH HIGH INTERNAL IMPEDANCE.

If (FIG. 3-9) e_g is the open-loop generator voltage, and r_g its internal impedance, e_i may be calculated from:

$$e_i = e_g - \left[\frac{e_g}{R_i + r_g}\right] r_g, \text{ where:}$$

$$e_g/(R_i + r_g)$$

represents the control current i_g so that e_i may also be expressed by:

$$e_i = e_g - i_g r_g$$

We can also (analytically) convert the generator into a current source capable of delivering a signal current i_g. (See FIG. 3-10.) In this case the transfer function (Eq. 2) simplifies to:

$$e_o = -i_g R_f.$$

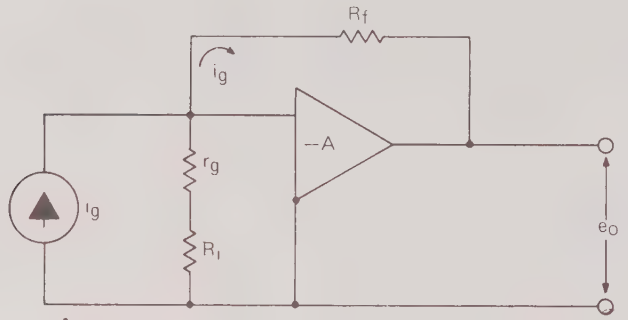


FIG. 3-10 CURRENT GENERATOR AS AN INPUT SOURCE.

3-27 APPLICATIONS WITH SIMULTANEOUS A-C/D-C OUTPUT

3-28 There are many practical applications where it is required to add or subtract d-c levels to or from the a-c signal input. The BOP with its built-in bipolar d-c reference sources is ideally equipped for level shifting of a-c input signals.

Example 1: A negative-going triangular wave with an amplitude of 30 volts is desired from the output of a Model BOP 72–5M. The input source is a signal generator with a peak to peak amplitude of 10 volts, transformer coupled into a 600 ohm impedance. Fig. 3-11 shows the input signal and the output desired.

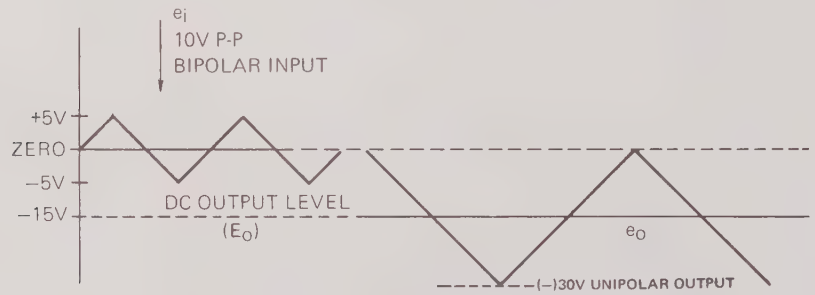


FIG. 3-11 UNIPOLAR OUTPUT FROM A BIPOLAR INPUT SOURCE.

In the above example, since we require an a-c output swing from zero to −30V peak and the input source is bipolar, we must produce a d-c output of −15V so that the amplified a-c signal can swing around this axis without going positive and produce the desired output which now has, in addition to the a-c signal, the desired d-c level shift.

3-29 The operational equation (Eq. 2) is now applied to both a-c and d-c conditions, and both a-c and d-c inputs are applied to the amplifier in a summing configuration to obtain the desired results.

a) D-C CONDITIONS:

$$E_o = -E_i \left[\frac{R_f}{R_i}\right] \qquad \text{(Eq. 2)}$$

E_o desired: −15V

Since the reference voltage ($E_i = -6.2V$) is available, the GAIN control (internal or external) is adjusted to 40 K ohms and the "REF." control (internal or external) such that the d-c output is equal to −15 volts. This adjustment establishes the necessary d-c bias level.

b) A-C CONDITIONS:

$$e_o = e_i\,(R_f/R_i);$$

e_o desired = 30V p-p

e_i max. = 10V p-p

The required gain (R_f/R_i) is therefore 3. Since the built-in feedback control (R_f = 40 K ohms) is used, the input resistance must be $R_i = R_f/3$ or 13.3 K ohm. If an amplitude control on the input source is available, R_i may be chosen somewhat smaller, and the proper signal amplitude can be adjusted on the generator. Alternately, R_i may be made adjustable in order to obtain the correct signal input. The d-c zero level may be corrected by adjusting the "REF." control on the front panel of the BOP. The necessary external connections to the BOP are shown in FIG. 3-12 below.

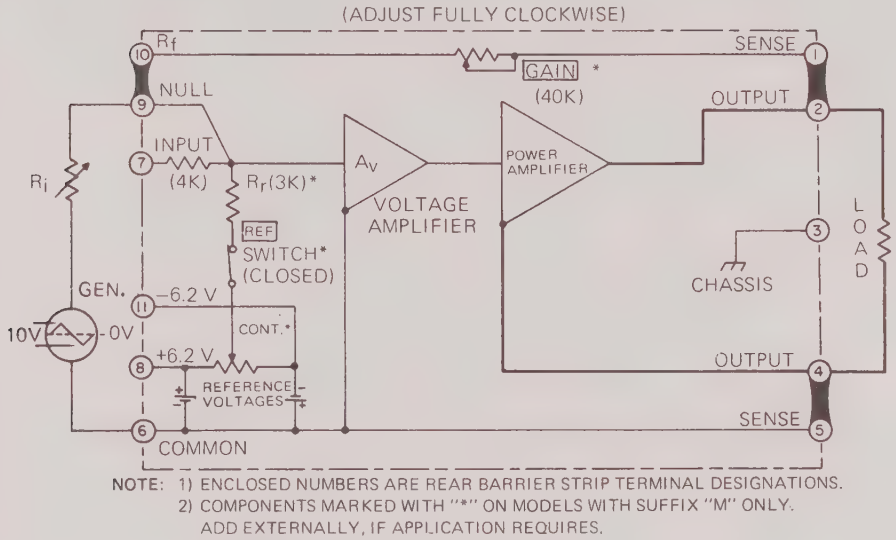


FIG. 3-12 CONNECTIONS FOR SIMULTANEOUS A-C/D-C OUTPUT (EX. 1).

3-30 Similar circuits with similar external connections as the example given (FIG. 3-12) may be constructed for a great variety of applications. If, for instance, a positive-going output is required (instead of the previous negative output) under otherwise identical conditions, the d-c output need only to be adjusted (by means of the "REF." control) to +15V. Unipolar signal sources (positive or negative) may be used with equal ease. An example is given below.

Example II: A bipolar, 70V p-p square-wave output is desired from a Model BOP 72–5M. The input source is a positive-going square-wave generator with a peak amplitude of 1 volt and with 1 K ohm source resistance.

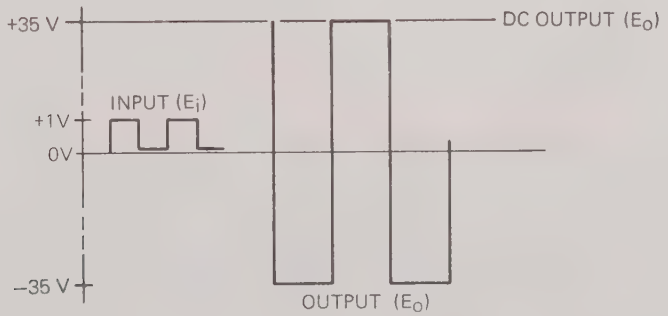


FIG. 3-13 BIPOLAR OUTPUT FROM UNIPOLAR INPUT SOURCE.

As seen from FIG. 3-13, for this input a "prebiasing" of the d-c output to +35V is needed, along with an a-c gain of 70 in order to produce the desired a-c voltage swing. We proceed as before:

a) D-C CONDITIONS:
With the GAIN control fully clockwise, adjust the output to +35V by means of the "REF." control.

b) A-C CONDITIONS:

e_o = 70V p-p

e_i = 1V p-p

$\therefore$ gain needed: $\frac{R_f}{R_i} = 70$ (37 dB)

Since with the built-in gain control R_f is given with 40 K, R_i must be 40 K/70≈570 ohms. Since the source resistance of our generator is 1 K ohm, however, we find the internal gain control cannot be used in this case. Instead, since R_f/R_i = 70, R_f must be 70 K ohms and is connected externally. The components are now connected externally as shown in FIG. 3-14, the d-c output readjusted with the "REF." control, and programming can commence.

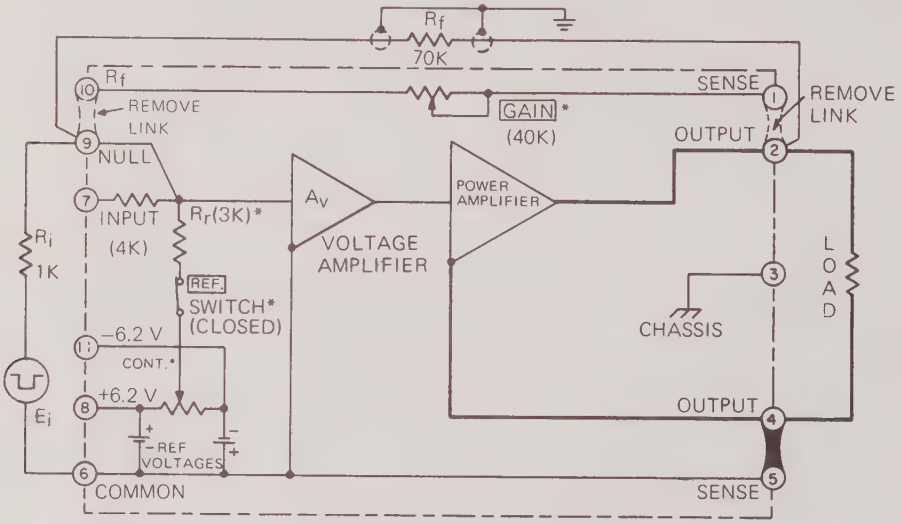


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FIG. 3-14 CONNECTIONS FOR SIMULTANEOUS A-C/D-C OUTPUT (EX.11)

3-31 CONSTANT CURRENT OUTPUT

3-32 The BOP Operational Power Supply operated as a constant current power supply or amplifier comes as close to an ideal current source as the state of the art permits. Due to its low output capacitance, the BOP exhibits excellent current recovery properties for rapidly changing loads. The recovery time for the output current in response to a voltage step-function (or load resistance change) is specified for the SLOW and the FAST mode of operation. (Refer to par. 1-13.)

3-33 To operate the BOP in the constant current mode, an external current sensing resistor is added. This resistor (R_S) yields a voltage drop proportional to the output current. The voltage drop (V_S) is now held constant in reference to either the internal d-c reference or to an input signal. In effect, therefore, the main difference between voltage and current mode operation is that in the former, the voltage across the load is regulated and in the latter, the voltage across R_S.

3-34 SELECTION OF THE CURRENT SENSING RESISTOR

3-35 R_S must be chosen with care. The high gain amplifier connected across it will indiscriminately respond to all changes produced. Variations not due to load current changes, such as those produced by noise and temperature rise, must therefore be kept as low as possible. The current sensing resistor should consequently be a wirewound, high quality unit with a temperature coefficient as low as possible and a wattage rating of at least 10 times the actual power dissipated. In addition, it should have the configuration of a four-terminal network. (Tepro TM series or equivalent.)

3-36 The value of R_S is chosen on the basis of a 1 volt sample at the maximum output current desired: $R_S = 1V/I_{O\,max.}$ where I_O is the output current. The absolute value of R_S is not critical and can be the nearest standard resistance available since I_O can be readily adjusted. The sample voltage (V_S) should not be chosen too high, however, since the detrimental effects of higher power dissipation must be avoided. On the other hand, with a too low value of V_S, the signal to noise ratio becomes a problem. The suggested 1 volt represents therefore a practical compromise for a large number of applications. If a large range of output current must be regulated, several sensing resistors must be used selectively to achieve optimum performance.

3-37 SELECTION OF THE CURRENT CONTROL RESISTOR

3-38 If the internal references in the BOP are used, current control is available by means of the "REF." control, and a fixed "coupling" resistor (R_C) may be used to complete the closed-loop circuit. Since a nonlinear control is not always desirable, however, the coupling resistor may be made variable and the "REF." control left at a fixed value, thus providing linear current control. Actual values may be calculated by referring to the simplified circuit shown in FIG. 3-15.

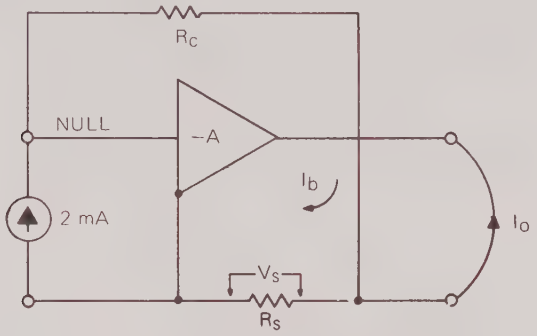

FIG. 3-15 CURRENT REGULATOR, SIMPLIFIED.

The internal reference source delivers 2 mA to the null junction. At balance, 2 mA control current must flow so that $I_bR_C = I_oR_S$. If, therefore, R_S was selected to drop 1 volt at a certain I_o, R_C must be 500 ohms since we selected a control current (I_b) of 2 mA. Practical component selection will be demonstrated by means of examples below.

3-39 STANDARD CONSTANT CURRENT REGULATOR

3-40 FIG. 3-16 shows the BOP Operational Power Supply/Amplifier connected as a continuously variable, d-c constant current power supply with reversible polarity.

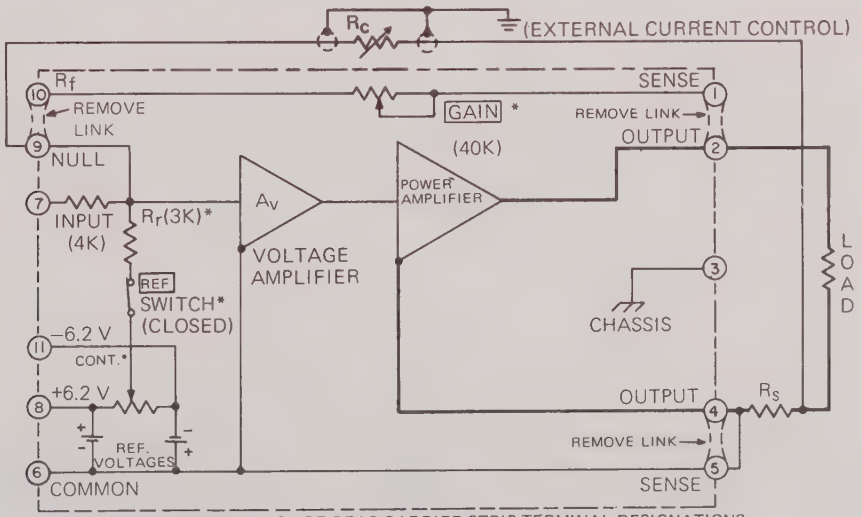

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FIG. 3-16 STANDARD CONSTANT CURRENT REGULATOR.

As indicated previously, control is possible two ways: with the built-in "REF." control and a fixed coupling resistor R_C (nonlinear); or setting the "REF." control to 2 mA (either polarity) and making R_C a variable resistor (linear control). In the latter case, control can then be effected remotely by rheostat or step switches with precision resistors (programming by resistance) as described in paragraph 3-16 for the standard voltage mode operation.

3-41 CONSTANT CURRENT AMPLIFIER MODE

3-42 If the internal d-c reference source is disconnected ("REF." switch "out") and an a-c signal source is applied to the input as shown in FIG. 3-17, the BOP functions as an amplifier as described in previous paragraphs. Similar criteria for selection of feedback components and identical limitations apply as for the circuitry in the constant voltage mode. If input sources have a d-c component, for example, it can be either eliminated or the output level can be shifted to accommodate the input. In these cases the "REF." switch is transferred to the "in" position and the d-c level adjusted until the desired output wave shape is achieved as observed with an oscilloscope parallel to the load. FIG. 3-17 shows the connections for standard amplifier operation in the constant current mode.

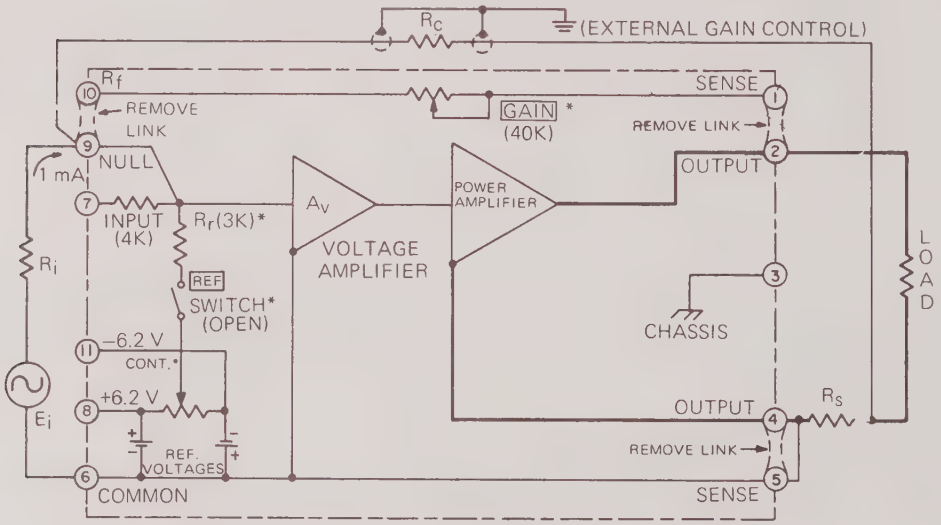

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FIG. 3-17 CONNECTIONS FOR CONSTANT CURRENT AMPLIFIER.

3-43 Variations on the standard amplifier circuit (FIG. 3-17) to accommodate specific operating requirements can be readily implemented by calculating the external component values to suit the application. The transfer function for the constant current mode is used for this purpose:

$$I_o = I_b\,(R_c/R_s),$$

where I_b is the control current from the input source, or:

$$I_b = e_i/R_i$$

As long as I_b = 2 mA is available from the input source, the circuit shown in FIG. 3-17 may be used. Linear gain control can be achieved by making R_c a variable resistor. D-C components may be added or subtracted by means of the internal "REF." sources as previously described for operation in the voltage mode. If less control current is available from the input source, or higher value sensing resistors are used for lower maximum output currents, the control resistor must be recalculated. If, for example, our input source has a maximum amplitude of 10V and a source impedance of 25 K ohms, the available control current is 10V/25 K ohms = 0.4 mA. If we desire a maximum output current of 1 ampere, the sensing resistor is selected by $V_s/R_s = I_o$, 1V/1A = 1 ohm. The actual power dissipation of R_s = 1V (1A) = 1 watt. A 10 watt wirewound unit is selected for R_s. Since a gain of I_o/I_b = 1A/0.4 mA = 2500 is required and R_c/R_s must equal this ratio, the value of R_c equals 2500 ohms. A wirewound, precision rheostat of that value will provide linear control of the output current.

3-44 SERIES OPERATION

3-45 The BOP POWER SUPPLY/AMPLIFIER may be connected in series with an identical unit to achieve increased voltage output. Several precautions must be observed, however, to insure successful operation:

a) The nature of the BOP circuitry does not permit series connection with INDIVIDUAL output control. A "master/slave" configuration is recommended instead, operating into separate—or into a common load.

b) The "current limit" controls of the SLAVE supply must be adjusted to a slightly higher value than those of the MASTER supply, if maximum rated current output is expected from the series connected BOP's. This will insure the necessary lead of the MASTER supply in the process of current limiting.

c) The setup procedure described below should be followed closely. DO NOT ADJUST THE CURRENT LIMIT CONTROLS TO VALUES GREATER THAN 5.6 AMPERES (MODEL BOP 72–5) AND 1.75 AMPERES (MODEL BOP 72–1.5). Although this may be possible (due to component tolerances), increased dissipation in the pass element sections with possible destruction of the transistors may result.

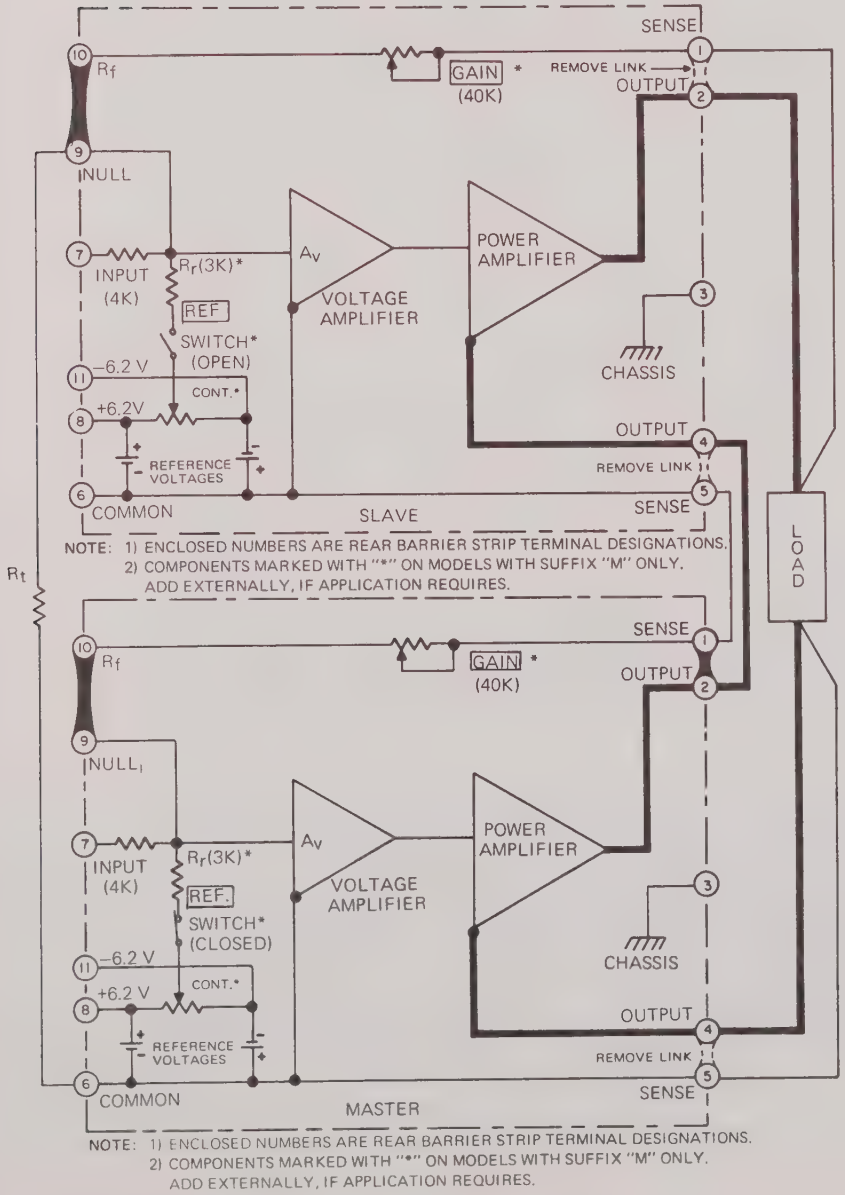


FIG. 3-18 SERIES OPERATION INTO SINGLE LOAD.

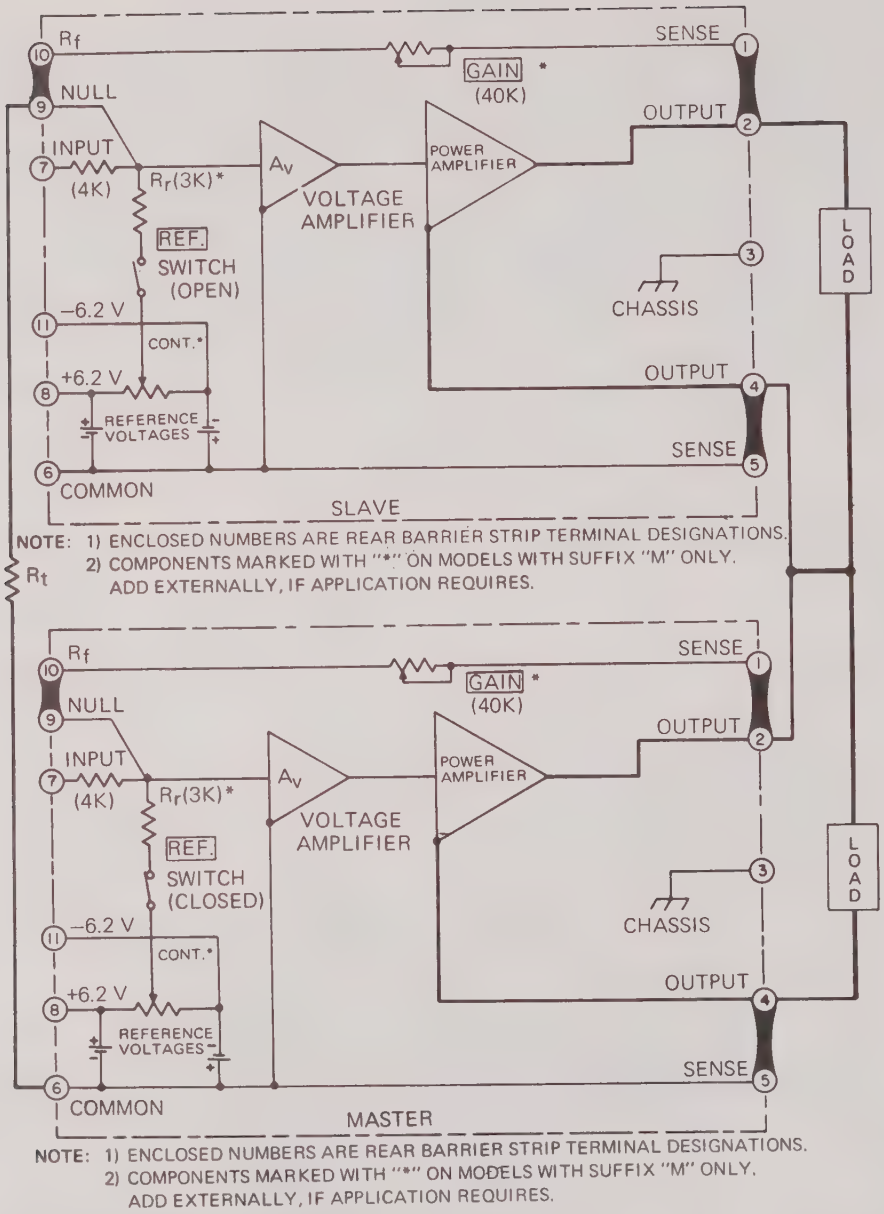


FIG. 3-19 SERIES OPERATION INTO SEPARATE LOADS.

3-46 SETUP PROCEDURE (Example for BOP 72–5)

a) PRELIMINARY ADJUSTMENTS. Since two sets of series regulator transistors are used in the BOP Power Supply/Amplifiers, there are two current limit controls which are factory-set to limit at a short circuit current of 5.5A d-c (Model BOP 72–5) and 1.65A d-c (Model BOP 72–1.5). For a series connection of two BOP units, the two current limit controls of the SLAVE supply must be reset to limit at a slightly higher value (to 5.6A on Model BOP 72–5 and 1.75 on Model BOP 72–1.5.) This will permit the full output current from the series combination and insure proper current limiting sequence (first MASTER, then SLAVE).

b) CURRENT LIMIT ADJUSTMENTS, SLAVE UNIT. Connect an accurate ammeter, such as the Weston Model 931, across the output terminals of the unit designated as the SLAVE. Turn the "REF." control fully counterclockwise and place the "REF." switch in the "IN" position. Turn POWER switch "ON." Observe the external ammeter. Adjust the GAIN control until output current does no longer increase. The short circuit current will be approximately 5.5A.

c) Locate the two "I_O Limit" controls (R35, R37) and the MODE switch (S1) on the printed circuit board. (Refer to the location diagram, FIG. 2-3.) Turn R37 slowly clockwise until the ammeter shows an increased short circuit current of about 5.6A. Turn POWER switch "OFF." Reverse polarity of the external ammeter. Turn "REF." control fully clockwise.

d) Turn POWER "ON." The ammeter should again show approximately 5.5A. Adjust the short circuit current by turning R35 slowly clockwise until 5.6A is reached. This completes the preliminary adjustment on the SLAVE unit.

e) The two BOP units can now be series connected as shown in FIGS. 3-18 or 3-19. Some load connections may require the operation of the BOP combination in the SLOW mode. Locate the MODE switch (S1) by referring to FIG. 2-3 and transfer both MASTER and SLAVE supplies to the SLOW position if a-c instability occurs.

f) As seen from FIG. 3-19, the output of the SLAVE supply is completely dependent upon that of the MASTER and in fact "tracks" the MASTER supply in an exact ratio of 1:1 if both GAIN controls are set to the same value and if R_t is selected such that:

$$R_{VCS}/R_t = 1, \text{ since:}$$

$$E_{os} = E_{om}R_{VCS}/R_t, \quad \text{where:}$$

E_{om} = Output Voltage, "Master"

E_{os} = Output Voltage "Slave"

R_t = Tracking Resistor.

In this case, $E_{om} = E_{os}$, where E_{os} is the SLAVE output voltage since $R_{VCM} = R_{VCS}$, i.e., the setting of the two GAIN controls is identical. If, for example, in the connection shown in FIG. 3-19, the voltage across both loads must be 60 volts, the "REF." control of the MASTER is set to the desired polarity and the GAIN control to the required 60 volts. A 30 K ohm resistor for R_t connected as shown will result in a control current of $E_{om}/R_t = 2$ mA and consequently in a SLAVE output of:

$$E_{os} = 2 \text{ mA } (R_{VCS} = 60 \text{ volts (if } R_{VCS}) = 30 \text{ K})$$

where R_{VCS} is the GAIN control resistance of the SLAVE unit. Both SLAVE and MASTER output are thus equal and track in a 1:1 ratio. The tracking ratio may be altered by either changing the GAIN control settings by replacing the built-in GAIN controls with external resistors or by selecting the value of R_t such that the desired tracking ratio is achieved. Amplifier operation of the MASTER supply as described in previous paragraphs may be used. The amplified output will either appear on both loads simultaneously, or if a common load is used, twice the output is applied to the load.

3-47 PARALLEL OPERATION

3-48 Two (or more) BOP Operational Power Supplies may be connected in parallel for increased output current delivery. As shown in FIG. 3-20, the two supplies are connected for d-c constant voltage operation and can deliver twice the rated output current of a single unit. Although local control is shown, they can be remotely controlled by resistance or operated as an amplifier as indicated previously for the single unit. Equal current sharing is achieved by selecting equal values for the current sensing resistors (R_S) and by keeping the output leads (drawn heavy in FIG. 3-20) as short as possible. For control of an output current of 5A d-c per unit, the sensing resistors (R_S) should be 0.1 ohms, 50 watt each. For other currents R_S can be calculated to drop approximately 0.5 volt for the desired maximum current. Although the individual units are protected by their current limiting circuits, a common power line connection with common a-c power "on" is recommended.

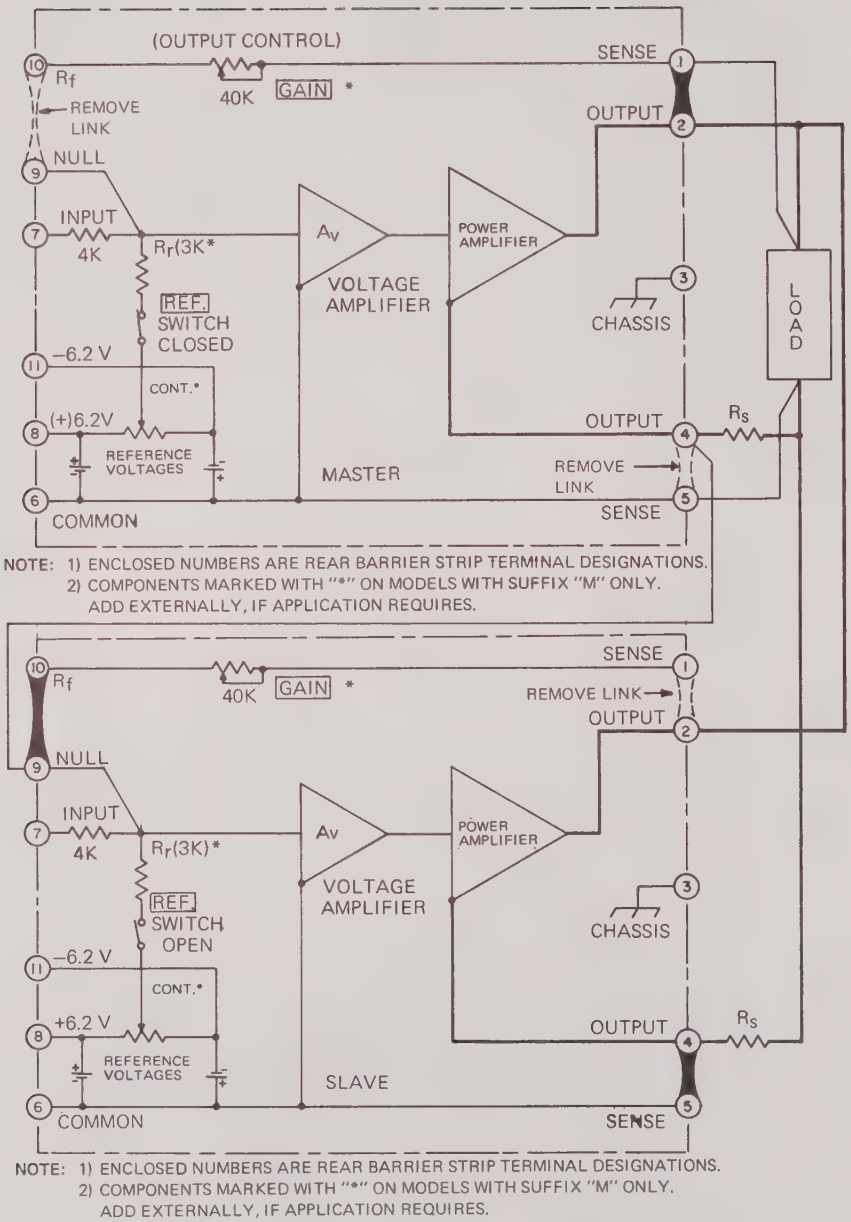


FIG. 3-20 PARALLEL OPERATION OF BOP OPERATIONAL POWER SUPPLIES.

SECTION IV – THEORY OF OPERATION

4-1 GENERAL

4-2 This section contains a short review of the principles of "operational" theory with special reference to the BOP Operational Power Supply/Amplifier. The scope of this manual allows only a simplified mathematical analysis, and the standard texts on linear amplifiers and feedback techniques should be consulted if a more extensive treatment is desired.

4-3 ANALOGY POWER SUPPLY – AMPLIFIER

4-4 Operational amplfifiers are high-gain, d-c coupled amplifiers which when internally stabilized and used in a closed-loop configuration exhibit linear gain characteristics depending only on the external feedback components.

4-5 Since a modern d-c regulated power supply contains such an amplifier in a closed-loop arrangement and in series with a power amplifier booster (consisting of driver stages and series regulators), it can be used as an amplifier if several conditions are fulfilled:

a) The large, bandwidth restricting output and feedback capacitors (C_O and C_f) must be removed.

b) The amplifier must be stabilized with lag networks for a gain/frequency roll-off of 6 dB per octave.

c) The input of the amplifier must be made accessible.

The result is an "Operational Power Supply/Amplifier" which may be analyzed in operational terms and used either in the d-c power supply mode (when connected to a d-c reference source) or as an amplifier with external input sources. (Refer to FIG. 4-1.)

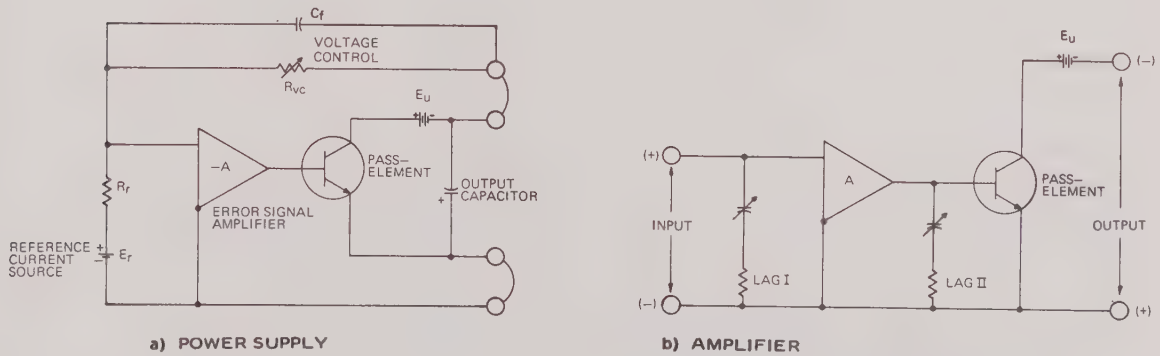


FIG. 4-1 POWER SUPPLY/AMPLIFIER CONVERSION.

4-6 In the BOP all of the above conditions have been satisfied. In addition, this instrument contains bipolar, precision d-c reference sources and a push-pull output stage providing (see FIG. 4-2):

a) Continuous d-c output from its maximum rated negative output voltage, over zero, to its maximum rated positive output voltage.

b) With the d-c reference disconnected and an a-c input source, high power bipolar a-c output with a peak-to-peak amplitude of twice the rated d-c output.

c) Combined a-c and d-c outputs, using the internal references as bias or level shifting sources with simultaneous a-c input signals in a summing configuration.

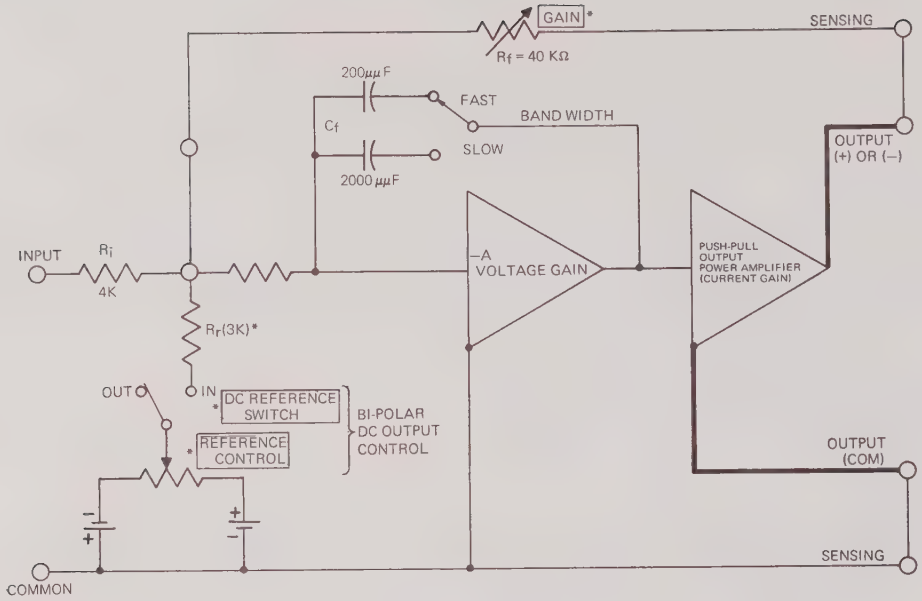


FIG. 4-2 BOP OPERATIONAL POWER SUPPLY, SIMPLIFIED DIAGRAM.

4-7 THE IDEAL AMPLIFIER

4-8 For the purpose of analysis, an ideal model of the operational amplifier is proposed, and the following assumptions are made:

a) The input terminal (null junction) will not conduct current to or from the amplifier.

b) The open-loop gain is very large ($A \rightarrow \infty$).

c) The input voltage ϵ approaches zero when the feedback loop is closed ($\epsilon \rightarrow 0$).

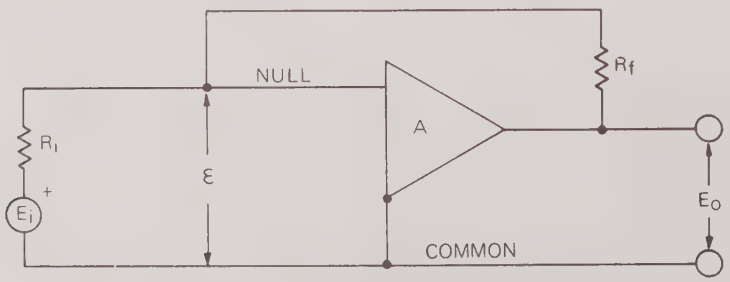


FIG. 4-3 MODEL OF IDEAL OPERATIONAL AMPLIFIER WITH FEEDBACK (INVERTING CONFIGURATION).

4-9 Refer to FIG. 4-3. Since (by the previous assumptions) the currents in R_f and R_i are equal, Kirchhoff's loop equation may be written as:

$$\frac{E_i - \epsilon}{R_i} + \frac{E_o + \epsilon}{R_f} = 0$$

By definition, $E_o = -A\epsilon$, where A represents the "open-loop" gain. Also:

$$\epsilon = \frac{E_o}{A}$$

If we let $A \to \infty$, $\epsilon \to 0$, then the original loop equation reduces to:

$$\frac{E_i}{R_i} + \frac{E_o}{R_f} = 0$$

or in the more familiar form:

$$E_o = -E_i \frac{R_f}{R_i}$$

which is recognized as the (ideal) transfer function of an operational amplifier in the inverting configuration.

4-10 THE PRACTICAL AMPLIFIER

4-11 The closed-loop relationships derived for the ideal model of the operational amplifier may be applied to the practical case with very small predictable errors which in addition can be compensated for. The "ideal" amplifier equation for example, may be used to calculate the magnitude of the feedback and input components with negligible errors, which will be well within the component tolerances. In evaluating the d-c performance, however, these errors cannot be neglected.

4-12 AMPLIFIER OFFSETS. In developing the ideal amplifier model, we tacitly assumed the null junction voltage and current to be zero, causing the "ideal" equation to be valid. In reality, however, nonidealities do exist at the null juction or input terminal of the amplifier. These errors are of the form of an offset voltage (E_{io}) and an offset current (I_{io}). The modified version of the amplifier model can be shown with these error sources as in FIG. 4-4.

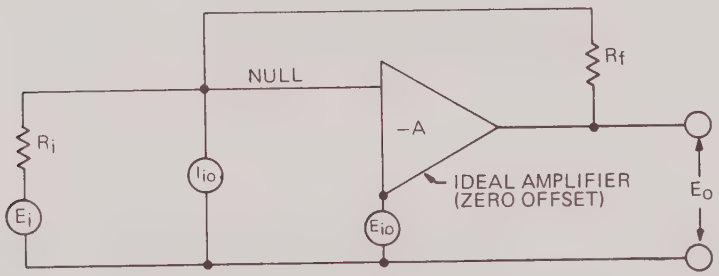


FIG. 4-4 AMPLIFIER WITH INPUT OFFSET SOURCES.

4-13 Although the initial values of both offsets may be zeroed by compensating sources of opposite polarities (as in the BOP), their VARIATIONS with a-c input line, output load, temperature and time do appear at the input and are specified as ΔE_{io} and ΔI_{io} in Section I and repeated here:

SPECIFICATION	VOLTAGE AMPLIFIER OFFSETS		6.2V REFERENCES
	ΔE_{io}	ΔI_{io}	
SOURCE: 105–125 or 210–250V a-c	<0.1 mV	<10 nA	<0.0005%
LOAD: No Load/Full Load	<1.0 mV	<10 nA	N.A.
TIME: 8 Hours (Drift)	<0.1 mV	<50 nA	<0.005%
TEMPERATURE: Per °C (Coefficient)	<0.05 mV	<50 nA	<0.005%

4-14 Considering both offset variations, the modified expression for the output voltage (with the initial or fixed parts of E_{io} and I_{io} nulled) becomes:*

$$E_o = E_i \frac{R_f}{R_i} \pm \Delta E_{io} \left[\frac{R_f}{R_i}\right] \pm \Delta I_{io} R_f \quad \text{(Eq. A)}$$

Ideal part

Output error due to offset voltage.

Output error due to offset current.

*The error term: $\pm \Delta E_i \frac{R_f}{R_i}$ is considered a secondary effect in this analysis.

As seen from Equation A, the offset voltage variations (ΔE_{io}) are multiplied by unity plus the gain ratio R_f/R_i to obtain its contribution to the output voltage change, while the offset current variations are multiplied by the value of the feedback resistor (R_f). The separation of the specifications for ΔE_{io} and ΔI_{io} not only allows an analysis of the contributions from each offset variation but also permits component selection such as to minimize the effects of either offsets or find an acceptable compromise.

4-15 Practical examples will illustrate the usefulness of the concept:

a) For an application requiring a gain of 10, an operational programming circuit is to be set up with a Model BOP 72–5(M). From the table of specifications the change in offset voltage due to a-c input source variations is specified as:

$$\Delta E_{io} = 0.1 \text{ mV}$$

$$\Delta I_{io} = 10 \text{ nA}$$

If we let R_i = 100 K ohms, then for R_f/R_i = 10, we need R_f = 1 megohm. The expected output effect due to a-c line changes are (from Eq. A):

$$\Delta E_o \text{ (due to a-c input source variations)} = \Delta E_{io}\left[\frac{R_f}{R_i} + 1\right] + \Delta I_{io} R_f$$

$$= 0.1 \text{ mV } (10+1) \quad + 10 \text{ nA } (10^6 \text{ ohms})$$
$$= 1.1 \text{ mV} \quad + 10 \text{ mV}$$

ΔE_o due to offset voltage change — ΔE_o due to offset current change

The contributions of ΔI_{io} are seen to be almost ten times that of ΔE_{io} due, of course, to the choice of a relatively large feedback resistor. Generally, in low gain applications, it is wise to select lower values for the feedback and input resistors if the loading on the input source will permit it. If, for example:

$$R_i = 10 \text{ K and } R_f = 100 \text{ K}$$

(retaining the previous gain ratio of R_f/R_i = 10), ΔI_o would only be 1 mV, calculated similar to the previous results.

b) Using the same amplifier in an application with a required operational gain of 100, we select R_i to be 1 K ohm and R_f = 100 K, thus establishing the desired gain ratio (R_f/R_i = 100). For the choice of input and feedback elements, we find the output effect due to a-c input source variations to be:

$$\Delta E_o = 0.1 \text{ mV } (100 + 1) \quad + 10 \text{ nA } (10^5 \text{ ohms})$$
$$= 10.1 \text{ mV} \quad + 1 \text{ mV}$$

ΔE_o due to offset voltage change — ΔE_o due to offset current change

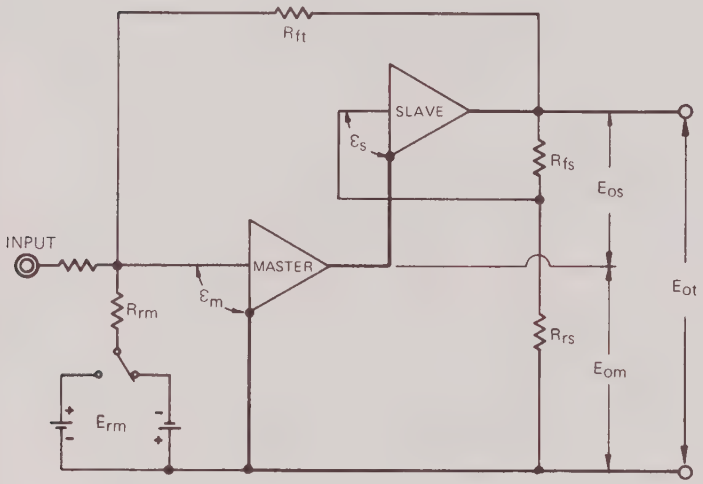
In this case the contribution from ΔE_{io} is dominant. Its effect can only be reduced by externally limiting wide variations of the a-c input source. Similar calculations to the above examples may be made to predict the output effects due to load changes, temperature variations or drift (changes in output voltage with time).

4-16 GAIN FREQUENCY CHARACTERISTICS (Please refer to Sect. III, FIG. 3-7 and FIG. 4-2, Sect. IV)

4-17 A flat frequency response to greater than 500 kHz is readily obtainable from the push-pull power amplifiers since no voltage gain is requested from this part of the BOP. Since the voltage amplifier is stabilized with internal resistor/capacitor networks, the frequency characteristics are determined by R_iC_f only. C_f can be selected by an internal slide switch for two unity gain crossover frequencies. In the SLOW position the instrument is unconditionally stable for any closed-loop gain (including 100% feedback) and for any amount of capacitive loading at the output. The maximum full power frequency response in this position is approximately 2 kHz. In the wide-band position (FAST), capacitive loading is restricted to 0.001 μF, maximum. In this position, however, with a unity gain crossover frequency of 300 kHz, the instrument is still stable for any closed-loop gain including 100% feedback. As seen from the gain vs. frequency plot (Bode plot) shown in FIG. 3-7, the theoretical frequency response of the instrument with, for example, a closed-loop gain of 10 (20 dB) is (in the FAST position) approximately flat to 30 kHz. However, due to capacitive loading at the amplifier output, actual frequency response is about 20 kHz.

4-18 EQUIVALENT CIRCUIT ANALYSIS (Refer to FIG. 4-5.)

4-19 The foregoing paragraphs on error analysis and gain frequency characteristics (refer to pars. 4-10, 4-16) are fully applicable to amplifiers in the "master/slave" configuration such as those in the BOP 72 Series. Although two amplifiers are used in a series connection, control is exercised by the "master" section alone while the main feedback operates on the series combination. The error sources (E_{io}, I_{io}) of the "slave" section are similarly in series with those of the "master" section and are corrected here only. As a result the representation of the BOP 72 Series as a single amplifier remains valid. The transfer function for the "master/slave" configuration of the BOP 72 Series can be developed from the equivalent diagram below (refer to FIG. 4-5), where:



E_{ot} = Total output voltage.
E_{om} = Master output voltage.
E_{os} = Slave output voltage.
R_{ft} = Feedback resistor, total.
R_{fs} = Feedback resistor, slave.
R_{rm} = Reference (input) resistor, master.
R_{rs} = Reference (input) resistor, slave.
E_{rm} = D-C reference voltage, master.
ϵ_m = Error voltage, master.
ϵ_s = Error voltage, slave.

FIG. 4-5 EQUIVALENT CIRCUIT, BOP 72 SERIES.

4-20 As seen from the diagram, the total voltage (E_{ot}) is the sum of the output voltages of the "master" and "slave" sections:

$$E_{ot} = E_{om} + E_{os} \qquad \text{(Eq. 1)}$$

Assuming an ideal equivalent circuit (error sources E_{io}, $I_{io} = 0$), the inputs to the individual amplifiers (MASTER, SLAVE) must be zero with respect to their individual common terminal ($\epsilon_m \mu \epsilon_s = 0$) for a steady-state condition. In this case we can write a balancing equation around the total feedback path:

$$\frac{E_{rm}}{R_{rm}} = \frac{E_{om} + E_{os}}{R_{ft}} \qquad \text{(Eq. 2)}$$

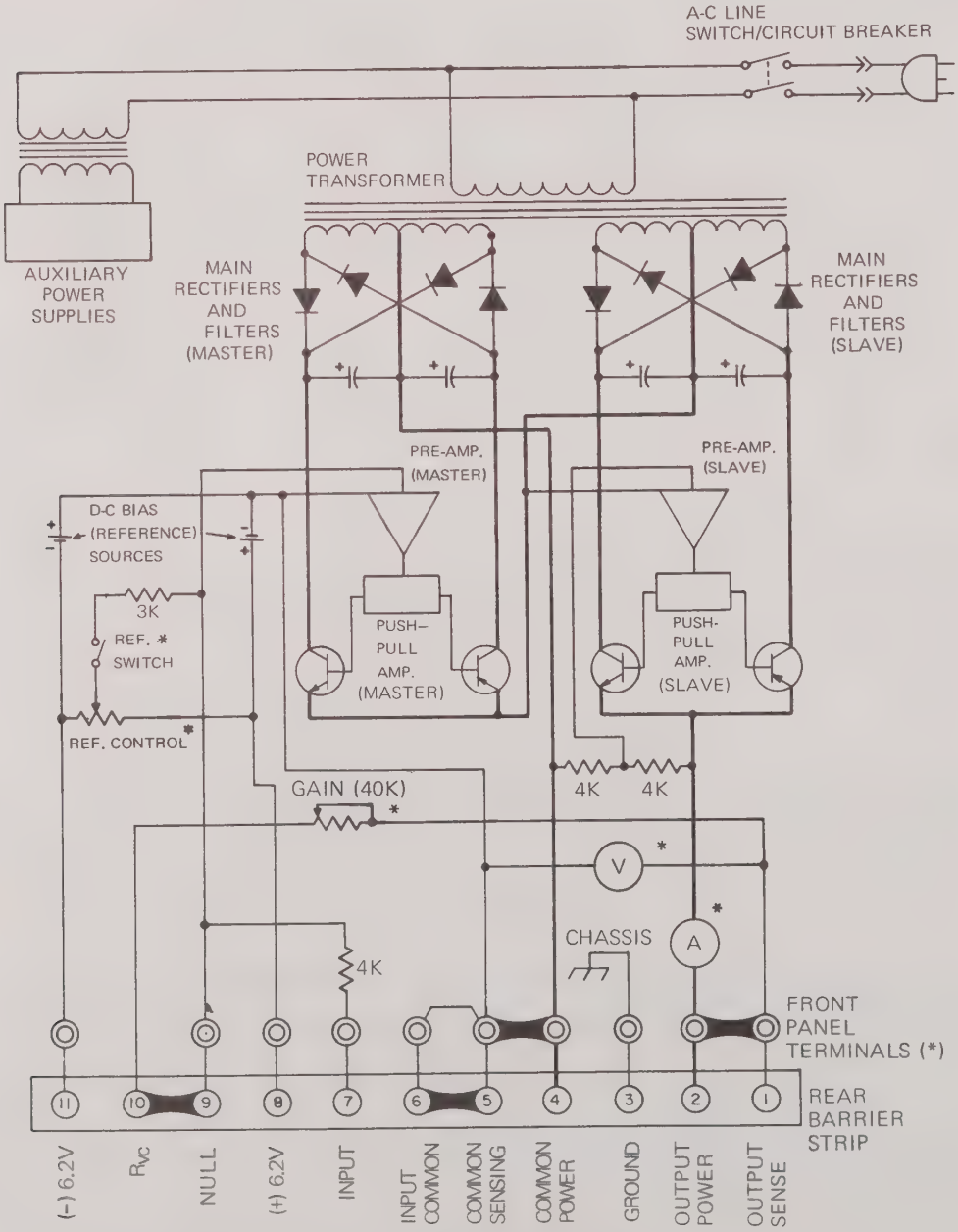
Substituting (Eq. 1) into this expression (Eq. 2) and solving for the total output voltage (E_{ot}), the transfer function for the total series combination can be expressed by:

$$E_{ot} = E_{rm}\left(\frac{R_{ft}}{R_{rm}}\right) \qquad \text{(Eq. 3)}$$

It is seen that the output voltage is therefore a function of the input voltage (E_{rm}) multiplied by the ratio of the feedback and the input resistor (R_{ft}/R_{rm}).

4-21 SIMPLIFIED SCHEMATIC DIAGRAM (Refer to FIG. 4-6.)

4-22 The POWER TRANSFORMER converts the a-c line voltage to the levels needed for production of the unregulated voltages for the MAIN and the AUXILIARY d-c supplies. There are two MAIN supplies developed with two separate secondary windings and both with individual rectifier and filter sections (MASTER and SLAVE). The twin MAIN supplies deliver their unregulated d-c power to their respective PUSH-PULL AMPLIFIER stages. The PUSH-PULL AMPLIFIER stages are series connected with the unregulated MAIN supplies and the output terminals and are driven by their respective PREAMPLIFIER stages. Only the "master" preamplifier is controlled. Its input is made available at the input terminals and/or can be biased by the built-in D-C BIAS (REFERENCE) SOURCES for "d-c only" output or biasing applications. The FRONT PANEL terminals, the output meters, the REFERENCE CONTROL potentiometer, the REFERENCE SWITCH and the GAIN control are part of BOP models with suffix "M" (metered) only. The controls and the metering must be connected externally (via the REAR BARRIER-STRIP) on meterless BOP models (without suffix "M") if the application so requires.



SIMPLIFIED SCHEMATIC WITH REAR CONNECTION DETAILS.

*Components used on models with suffix "M" only

4-23 CIRCUIT DESCRIPTION (Refer to Main Schematic, FIG. 6-4, 6-6.)

4-24 This section contains a description of the major circuitry of the Kepco BOP (72 V Series) Operational Power Supply/Amplifier. The BOP consists of a full rack main chassis assembly (A2) with attached front panel and contains a total of thirteen (13) subassemblies (A1, A3 through A13), the main power transformer (T201), the auxiliary transformers (T202, 203), the main rectifier and filter components (C201–204, CR201–208, L201–204) and the distribution harnesses. The subassemblies and the main chassis are interconnected by printed circuit connectors. The interconnecting diagram (FIG. 6-1) represents a symbolic illustration of all plug-in connections to the main wiring harness. The identification of all connectors coincides with that of the main schematic diagram. Any component in the main schematic can be readily traced to its location on a subassembly by means of its reference designation and the information given in the interconnecting diagram (FIG. 6-1).

4-25 A-C INPUT CIRCUIT (Refer to Main Schematic and FIG. 4-7.)

4-26 The a-c line power is introduced through the three-wire line cord with safety plug.* The line cord wire connected to the grounding pin of the safety plug is connected directly to the metal chassis of the BOP. If a properly grounded a-c power outlet is therefore used, safety grounding is automatically provided.

4-27 Once the a-c circuit breaker/a-c power switch (CB101) is closed, the front panel a-c power indicator (DS101) will energize, and a-c line power is applied simultaneously to the primary windings of the main transformer (T201), the auxiliary transformers (T202, 203) and the fan motors (B201, 202). The dual primary windings on the main power transformer (T201) are either connected in parallel (for 115V a-c operation) or in series (for 230V a-c operation). The auxiliary transformers and the fan motors (T202, 203, B201, 202) are always connected to 115V a-c even if the main transformer primary connections are altered for operation on a 230V nominal a-c line.

4-28 (Refer to FIG. 4-7) The a-c circuit breaker/a-c power switch (CB101) is a dual coil device which not only serves as a manually operated a-c power switch but also automatically disconnects both a-c line wires to and from the a-c input circuit in case of an overload. While one coil of CB101 is connected in series with a primary winding on T201, the other is connected in series with both primaries of the auxilary transformers (T202, 203) regardless of the primary connection on T201 (shown for 115V a-c nominal line operation).

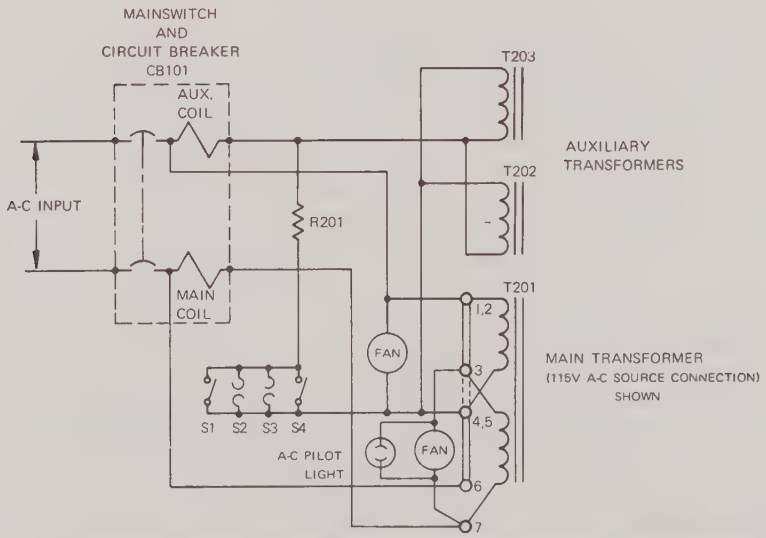


FIG. 4-7 BOP, A-C INPUT CIRCUIT, SIMPLIFIED.

Any overload either in the primary winding of the main transformer or in one of the auxiliary primaries will energize the associated circuit breaker coil sufficiently to disconnect the line from the instrument.

4-29 The "auxiliary" coil of CB101 is used for an additional protective function. It energizes and trips the circuit breaker if any one of the four switches (S1 through S4) should close. Two of the switches (S1, S4) are relay contacts from the discharge relays (K201, 202) in the master and slave supply. (See par. 4-51 for a description of the relay circuits.) The other two switches (S2, S3) are temperature-sensitive units located in the pass element heat sink assemblies (A5, A9). These thermal switches will close if the temperature in their respective environments becomes excessive.

*Used on metered models (suffix "M") only. On unmetered models, which have an a-c input barrier-strip, terminal "G" must be returned to a-c ground.

4-30 MAIN D-C SUPPLIES

4-31 The d-c output power is derived from the two secondary windings on the main transformer (T201). Each tapped secondary works into a bridge rectifier (CR201—204 and CR205—209) with following dual Π filters (Ç201, L201, C202, C203, L202, C204, for the "master" supply, C205, L203, C206, C207, L204, C208 for the "slave" section). In this manner the necessary unregulated voltage supply for the master, as well as the slave section is generated. All input capacitors are paralleled by bleeder resistors (R203 to R206). The main d-c supplies are the source for the output current delivered via the push-pull amplifier stages.

4-32 PUSH-PULL AMPLIFIER AND DRIVER

4-33 The power transistors for the push-pull amplifier stages are located on separate, highly efficient heat sink assemblies (A5, A9) and cooled by fans (B201, B202). Since the circuitry for the master heat sink assembly (A5) is identical with that of the slave assembly (A9), only the master assembly will be described here. Components in the master assembly are prefaced with the number "5" (e.g., Q501) while the corresponding slave assembly component would be prefaced with the number "9" (e.g., Q901).

4-34 Connected as a single-ended, push-pull amplifier stage and biased for class AB operation, the complementary PNP/NPN circuitry eliminates the need for an inverting stage. The NPN type transistors (Q501—Q506) are "in series" with the positive main power supply while the PNP type transistors are in series with the negative main source.

4-35 DRIVER STAGE (MASTER SECTION, A4). The base drive for the push-pull amplifier stage is derived from the principal driver stage (Q403) which in turn is driven by the main amplifier output stages (Q5) or by one of the current limit stages (Q8, Q9).

4-36 DRIVER STAGE (SLAVE SECTION, A8). The driver stage for the slave section functions identically to that of the master section except that the principal main driver transistor (Q803) is driven only by the slave amplifier output stage (Q605) since the slave section does not contain separate current limiting.

4-37 CURRENT LIMITING

4-38 Since the BOP 72 volt models make use of a master/slave arrangement, the current limiting stages can be confined to the master section alone. There are two current limiting stages, one for positive output with reference to "common" (NPN power transistors conducting) and the other for negative output (PNP power transistors conducting). Positive output produces a voltage drop across the sensing resistor (R1105) which increases with rising output current. The NPN current limit adjustment rheostat (R35) is preset such that the limiting stage (Q8) is biased "on" if the output current exceeds the maximum rated value. As the limiting stage (Q8) turns "on," the collector potential on the amplifier stage (Q6) is sharply reduced which in turn cuts down the drive to the final stage of amplification (Q5) and diminishes the drive to the NPN pass elements. As a consequence, limiting of the (positive) output current takes place. The action in the limiting circuit for the negative output is similar to the events described above. As the current flows through the pass elements in series with the negative output (PNP pass elements), it is monitored by the sensing resistor (R1104). If the preset voltage drop across the PNP current limit adjustment rheostat (R37) is exceeded by the voltage drop across R1104, the current limiting stage (Q9) turns "on." Acting on the constant current stage in the driver assembly (Q401 in A4) via Q302 (A3), the drive to the PNP pass elements is reduced until the negative current output decreases sharply.

4-39 VOLTAGE AMPLIFIER SECTION (MASTER, A1)

4-40 Since the push-pull amplifier stage has a large power gain but no voltage gain, the voltage amplifiers in the master and slave sections must produce the full output swing of the BOP (±72 volts). The master voltage amplifier (A1) consists of the input stage, several stages of voltage amplifications and an output stage. A matched pair of transistors on a common substrate (Q4) is used to provide maximum thermal stability in the input stage. A discrete pair of transistors on a common heat sink for thermal stability function as a voltage amplifier stage (Q7) operated from a constant current source (Q3). The last stage of amplification (Q6) is directly coupled to the emitter-follower output stage (Q5) so that the total phase shift of the amplifier is 180°. The input to the output stage contains the feedback network which serves as a bandwidth selector (S1). In position FAST, the feedback capacitor (C2) is 200 pF while in position SLOW, the bandwidth is reduced by paralleling C2 with an additional capacitor (C3, 2200 pF).

4-41 The input null juction of the master voltage amplifier is brought out to the rear barrier-strip (TB1301) as well as to the front panel (models with suffix "M" only) and is thus available for external programming. The offset current control (I_{io} null, R1002) is also connected to the null junction while the offset voltage control (E_{io} null, R1001) is connected to the other base of the differential input pair (Q4). Both nulling controls are recessed from the front panel and can be adjusted through access openings from the front. The d-c bias control circuit (models with suffix "M" only) consists of the reference voltage control ("REF.," R101) and the "In-Out" switch (S101) both located at the front panel and electrically connected to the null junction in a summing configuration. The reference voltage control (R101) is connected between two extremely stable (±) d-c current sources in the form of zener diodes (CR6, CR7). These bipolar sources are available at the rear barrier-strip (TB1301—8, TB1301—11) as well as on the front panel (models with suffix "M" only). The reference control may therefore be connected externally on unmetered models or for remote control purposes on all models.

4-42 If the d-c bias sources are not used, the input signal is introduced either via the NULL JUNCTION (without input resistor) or the INPUT terminal (with 4 K ohm input resistor). Signal flow through the master voltage amplifier will take place as described above. The total gain of the BOP will be determined by the magnitude of the input signal and the ratio of the GAIN control (R102—40 K ohm on models with suffix "M" only) and the input resistor:

$$G = \frac{E_o}{E_i} = \frac{R_f}{R_i'}$$ where: E_o = Total BOP output voltage.
E_i = Input voltage.
R_f = Gain control or feedback resistance.
R_i = Input resistance.

On BOP models with built-in GAIN control (R102 = 40 K ohm) and with the provided input resistor (R1004 = 4 K, provided on ALL models), the gain can be adjusted from zero to 10 since the GAIN control is a rheostat with a range from zero to 40 K ohms. On meterless BOP models the gain control must be connected externally to the rear barrier-strip terminals.

4-43 A single a-c feedback loop in the master voltage amplifier connected from the input stage (base of Q4) to the output (base of Q5) is used to achieve the two specified gain/frequency characteristics for the BOP. (See FIG. 4-5.) In the SLOW position of the bandwidth selector switch (S1), paralleling of two feedback capacitor values (C2, C3) provides for unconditional instrument stability under all loading conditions including 100% feedback and unrestricted capacitive loading with reduced bandwidth. In the FAST position of the selector switch, a smaller feedback capacitor is used. Maximum specified bandwidth is available, but capacitive loading is restricted to 0.0001 μF maximum.

4-44 If d-c output is desired or d-c biasing is needed, the reference control (R101 in models with suffix "M" or externally connected in meterless models) can be used to provide a positive or negative reference current. The d-c output of the BOP will in this case be equal to:

$$E_o = I_b R_f$$ (Eq. 2), where: E_o = d-c output voltage.
I_b = Control or reference current.
R_f = GAIN control or feedback resistance.

As seen from Eq. 2, the control or reference current (I_b) and the value of the feedback resistance (or the setting of the GAIN control) will determine the d-c output voltage (E_o). For any setting of the GAIN control (or value of feedback resistance), the reference or control current (I_b) in the metered BOP models (models with suffix "M") can be adjusted by the front panel "REF." control between approximately −2 mA and +2 mA. According to Eq. 2, the output voltage will correspondingly be equal to:

$$E_o = \pm 2 \text{ mA} \times 36 \text{ K ohms} = \pm 72 \text{ volts},$$

given a feedback resistance (or GAIN CONTROL setting) of 36 K ohms.

4-45 VOLTAGE AMPLIFIER SECTION (SLAVE, A6)

4-46 The voltage amplifier in the slave section is connected in series with that of the master section. It derives its input signal via the input resistor from the output of the master supply (refer to FIG. 4-6) so that its own output is completely dependent on the master supply. The slave amplifier is similar to that of the master supply, and signal flow takes place as described for the latter. (See par. 4-40.) The slave voltage amplifier does not contain offset controls, reference sources or bandwidth control components since as discussed previously, its output depends on the master amplifier section.

4-47 AUXILIARY ASSEMBLIES (A3, A7)

4-48 The auxiliary power sources for the master as well as the slave section consist of full-wave rectified, capacitor-filtered supplies for the overshoot protection circuits, the voltage amplifiers and the voltage amplifier output stages in the respective sections. The auxiliary assemblies (A3, A7) are identical except that the reference designators are prefixed "3" in the master section (A3) and "7" in the slave section (A7). The individual description below is therefore confined to the auxiliary assembly of the master section (A3).

4-49 OUTPUT STAGE POWER SUPPLY. This power source for the voltage amplifier output stage is derived from a secondary winding on the auxiliary transformer (T202). It is a dual d-c source (±60V) rectified by CR304, CR305 (positive side) and CR302, CR303 (negative side). The dual source is capacitor-filtered by C303 and C302 respectively. R301 and R302 are bleeder resistors parallel to the filter capacitors. The dual power supply provides the operating potentials for the output stage of the voltage amplifier.

4-50 AMPLIFIER POWER SUPPLY. This full-wave rectified (CR301) and capacitor-filtered (C301) power source is derived from a secondary winding on the auxiliary transformer (T202). The unregulated, filtered d-c is transferred to the amplifier assembly (A1 master, A6 slave) and further processed. A constant current stage (Q1 master, Q601 slave) feeds a string of zener diodes (CR2—CR5 master, CR601—CR603 slave) from which the operating voltages for the input stages are derived. In the master section only, the two reference sources are also derived from this supply. The two reference zener diodes (CR6, CR7) are temperature compensated devices. Their output (±6.2 volt nominal) is available at the rear barrier-strip (TB1301) as well as on the front panel (models with suffix "M" only). In metered models (models with suffix "M"), the reference control potentiometer ("REF.," R101) is connected across both zener voltages so that a d-c control current (±2 mA) can be applied to the null junction of the amplifier if the reference switch (S101) has been closed. In unmetered models this function may be readily duplicated by connecting an external reference control potentiometer to the appropriate rear barrier-strip terminals, if desired.

4-51 OVERSHOOT PROTECTION CIRCUIT. To prevent overshoot at a-c power shutoff or power failure, special circuitry has been provided to discharge the main filter capacitors and subsequently shut down the instrument. The circuitry is provided in both master and slave sections and is identical except for the different component reference designators as pointed out before. The master section circuitry is described below.

4-52 An auxiliary d-c power supply derived from a secondary winding on T202 and consisting of a bridge rectifier (CR306) and a filter capacitor (C304) is monitored for low voltage conditions or sudden a-c input power loss due to either on-off switching or power failure. The sensing element is an NPN transistor (Q301) which is biased for saturation via the voltage divider (R303, R305). Since the collector and emitter of Q301 are connected between gate and cathode of the SCR crowbar (CR1201) which in turn is connected across both main supplies, the SCR has very little forward bias and is normally "off." As soon as any voltage drop in the sensing divider (R303, R305) occurs, Q301 is biased towards cutoff thus producing a positive turn-on signal in the SCR crowbar (CR1201). As the SCR conducts, it effectively shorts out the main supplies and simultaneously energizes the relay (K201). The normally open contact of K201 closes and trips the main circuit breaker thus removing a-c power from the instrument. IMMEDIATE TURNON IS PREVENTED BY A TIME DELAY (approximately 2 sec.) until the main filter capacitors are discharged. The time delay circuit consists of a delay capacitor (C307) and a rectifier diode (CR308).

SECTION V – MAINTENANCE

5-1 GENERAL

5-2 This section covers maintenance procedures and calibration of the BOP Operational Power Supply/Amplifier as far as not covered previously in this manual. Conservative ratings of components and noncongested layout should keep maintenance to a minimum. If trouble does develop, however, the easily removed wrap-around cover in conjunction with the plug-in feature of all major component boards provide exceptional accessibility of the circuitry.

5-3 COVER REMOVAL

5-4 The wrap-around cover may be readily removed by loosening the four (4) holding screws on the top of the front panel, the five (5) holding screws on each side of the unit and two (2) holding screws on the rear of the cover.

5-5 FAN MOTOR

5-6 The fan motors in the BOP units have permanently lubricated bearings and do not require maintenance. The inside of all BOP's should be cleaned periodically to insure full cooling efficiency.

5-7 INTERNAL ADJUSTMENTS

a) CURRENT LIMIT CONTROLS. The output current limit controls (R35, R37) are factory-adjusted to limit the output current at 10% above the maximum rated value. Calibration is necessary only if components associated with the current limit circuitry have been replaced or if a lower limit is desired. The current limits are individually adjustable in the range from 65% to 110% of the maximum rated output current. The current limit potentiometers are located on the amplifier printed circuit board (PCB 1-A1, see FIG. 2-3 for location) and are readily accessible from the top of the unit. Adjustment takes place as follows:

1) Connect BOP as a power supply for negative output. Connect load so that the desired output current (plus 10%) is drawn from the unit.
2) Observe output ripple on the oscilloscope across the load. Turn "I_O Limit" control (R37) counterclockwise until the output ripple sharply increases. (This is the point at which current limiting takes place.) Turn R37 slightly clockwise until the output ripple appears just normal again.
3) Repeat above procedure by transferring to a positive output and adjusting R35 as described above. The current limit is now set to the new value.

b) METER CALIBRATION.* The built-in panel meter has been calibrated at the factory (in the "AC" position) for correct indication of the a-c output voltage using a true rms indicating reference. The meter may be recalibrated to any other reference desired by monitoring the output with the reference source and adjusting the calibrating rheostat (R18, see FIG. 2-3 for location).

*Models with suffix "M" only.

5-8 TROUBLE SHOOTING

5-9 The repair of precision power supplies and operational amplifiers requires a thorough understanding of the operational concept, experience with solid state circuitry and appreciation of the problems encountered in closed loop systems. Repair beyond simple part replacement and recalibration should therefore be handled only by personnel familiar with these concepts. "Trouble Shooting Charts" giving resistance and voltage ratings at various parts in the circuitry are of little value in feedback amplifiers and for this reason are not included here. Presented instead are:

a) Extensive Operational Theory (Section IV).
b) Parts Location Diagrams (Section VI).
c) Main Schematic with Voltage Readings on All Essential Points (Section VI).
d) Parts List (Section VI).
e) Circuit Description (Section IV).

It has been our experience that this material will provide the necessary information in the majority of all cases of equipment failure if handled by competent personnel. Kepco Field Enginnering Offices and the Kepco Repair and Engineering Applications Departments are always available for prompt service in difficult cases.

5-10 TEST MEASUREMENTS

5-11 GENERAL. Test measurements to verify the specifications of the operational power supply are often required as a part of incoming inspection following repairs or as a part of a regular maintenance procedure. Adequate test facilities and equipment as well as great care in the performance of these measurements are of prime importance to insure valid results. Since many measurements on operational power supplies and amplifiers require specialized test equipment and rigidly controlled environment conditions, only the more readily verifiable ones are described here.

5-12 MEASUREMENT TECHNIQUES. The importance of proper interconnection of test instruments and the device under test cannot be overemphasized. Indiscriminate connection of measuring devices to the output may cause erroneous readings of d-c output effects, offset parameters or output impedance. The following recommendations should therefore be followed when measurements are to be performed:

a) Connect equipment exactly as shown on the measurement setup diagrams (FIGS. 5-2, 5-3). Do not attempt to measure performance characteristics at the front terminals while drawing load current from the rear terminals (or vice versa).

b) Output current measurements require the use of a high quality, wirewound measuring resistor which should be of the four-terminal type and have a low temperature coefficient as well as a wattage rating of at least ten times the actual power dissipated (TEPRO Type TMK or equivalent).

c) Ripple and noise measurements require the strict adherence to sensible equipment grounding practices. There can be only one ground point in a test setup. All equipment is therefore operated off line ground, the equipment cases or ground connections brought to the unit under test, and the latter is then grounded at a single point.

5-13 TEST EQUIPMENT REQUIRED. The following represents a listing of equipment required to perform the suggested performance tests:

a) LINE STEP DEVICE OR VARIABLE TRANSFORMER capable of adjusting the power line from 105V to 125V a-c and rated to deliver the maximum input current for the instrument under test.

b) RESISTOR LOAD, adjustable to load the power supply to 10%, 50% and 100% in both voltage and current operating modes and equipped with a shorting switch.

c) VOLTAGE MONITOR. Differential or digital voltmeter with a resolution of at least 1 mV and a range covering the maximum output voltage of the instrument under test.

d) RMS READING VOLTMETER for ripple monitoring, Ballantine Model 320A or its equivalent.

e) OSCILLOSCOPE for output ripple observance, Tektronix Model 502B or equivalent. (Optional)

f) MULTIMETER for measuring pass element voltage and general trouble shooting measurements. 20 K ohm/V, Weston Analyzer Model 980 or its equivalent.

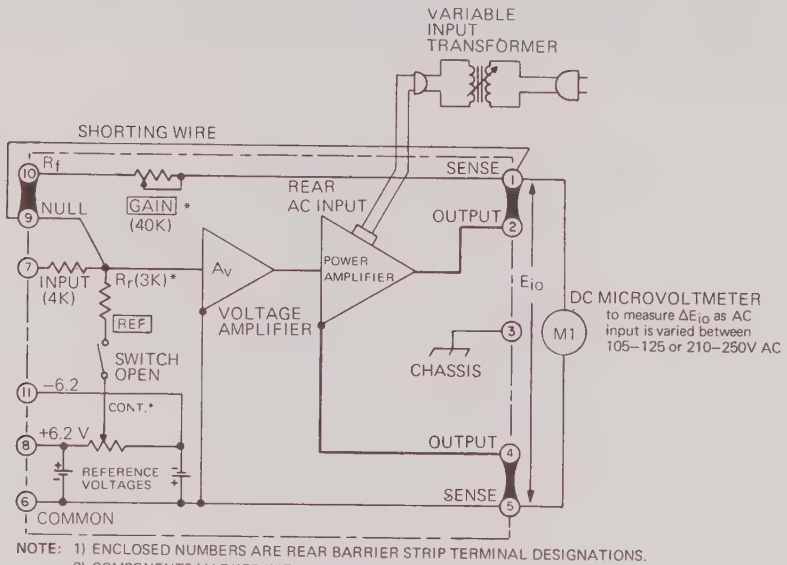
g) PRECISION D-C AMMETER with a range covering the maximum output current of the model under test. (Weston Model 931 or equivalent)

h) OSCILLOSCOPE for the measurement of the programming time constant., Tektronix Model 545A or equivalent.

i) SIGNAL GENERATOR for the measurement of the programming time constant, Hewlett Packard Model 211A or equivalent.

j) D-C MICROVOLT/AMMETER for offset measurements, Millivac Model MV-07C or equivalent.

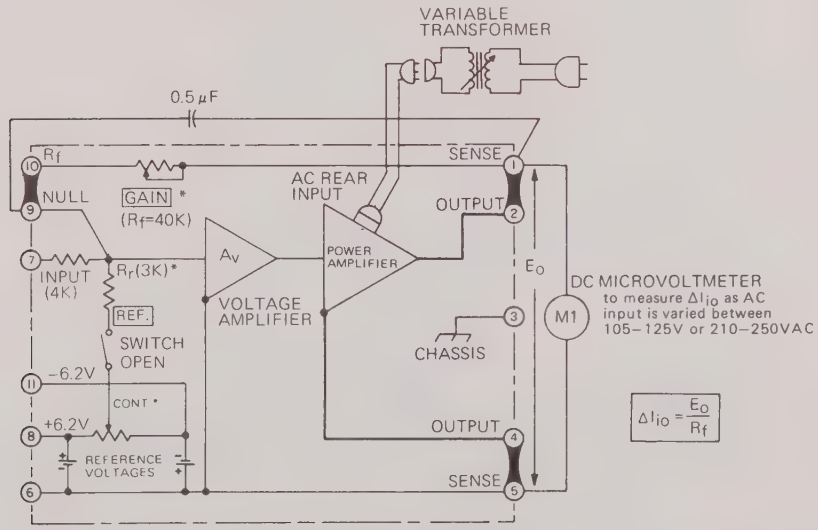
5-14 D-C MEASUREMENTS. Variations of the offset voltage (ΔE_{io}) and offset current (ΔI_{Io}) with a-c input source changes over the specified range are an excellent indication of the d-c performance of the operational power supply. These measurements may be readily duplicated by following the instructions and diagrams below:



NOTE: 1) ENCLOSED NUMBERS ARE REAR BARRIER STRIP TERMINAL DESIGNATIONS.
2) COMPONENTS MARKED WITH "*" ON MODELS WITH SUFFIX "M" ONLY.
ADD EXTERNALLY, IF APPLICATION REQUIRES.

FIG. 5-1 D-C TEST MEASUREMENTS (ΔE_{io} vs. A-C LINE).

a) Variations in Offset Voltage (ΔE_{io}). Measurements are made with the circuit shown in FIG. 5-1. Since the feedback terminals are shorted out and the input is disconnected, the operational gain is unity. Whatever offset voltage exists between null junction and common will be transferred directly to the output. Monitoring the output by means of a sensitive null detector while varying the A-C line input (or temperature or time if facilities permit) will allow measurement of ΔE_{io} at the output.

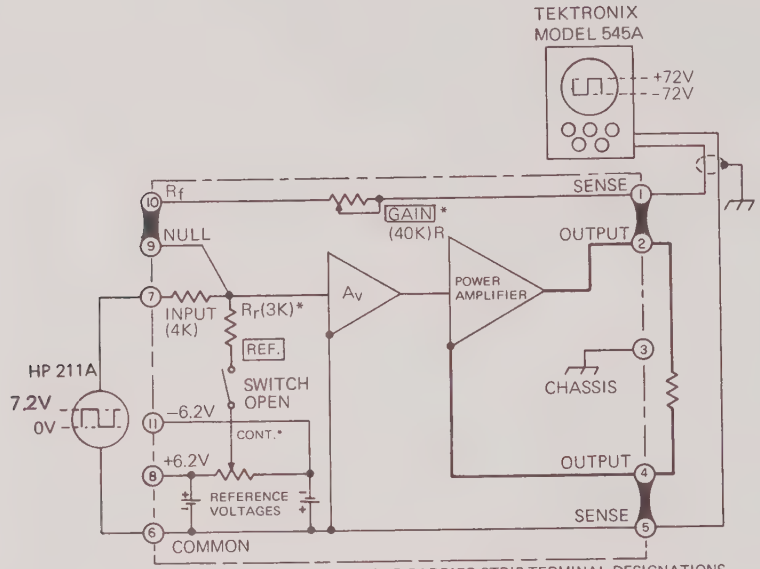


NOTE: 1) ENCLOSED NUMBERS ARE REAR BARRIER STRIP TERMINAL DESIGNATIONS.
2) COMPONENTS MARKED WITH "*" ON MODELS WITH SUFFIX "M" ONLY.
ADD EXTERNALLY, IF APPLICATION REQUIRES.

FIG. 5-2 D-C TEST MEASUREMENTS (ΔI_{io} vs. A-C LINE).

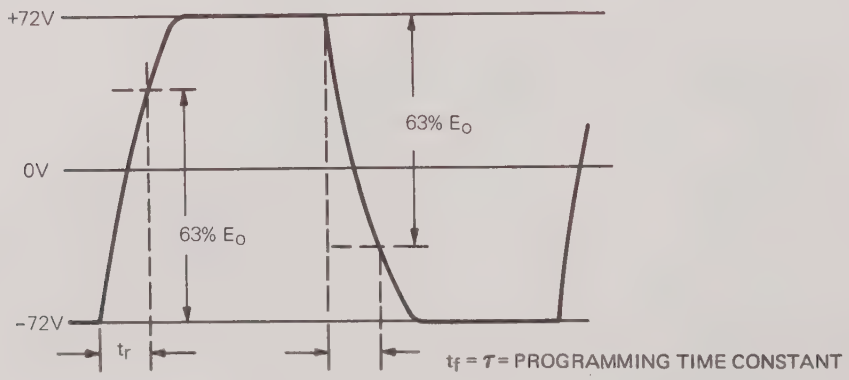
b) Variations in Offset Current (ΔI_{io}). Measurements are made with the circuit shown in FIG. 5-2. Since the offset current will have to flow through the feedback resistor, it produces an output voltage E_o which is equal to $I_{io}R_f$. If this output voltage is monitored while varying the a-c line input (or temperature or time if facilities permit) will yield an indication of ΔI_{io} when the output voltage is divided by the value of the feedback resistor

5-15 DYNAMIC MEASUREMENTS. Measurement of the programming time constant of the BOP Operational Power Supply/Amplifier is a convenient and simple way of verifying the dynamic performance of the instrument. The programming time constant is evaluated by measuring the fall time (worst case) at the output as the BOP is programmed with a square wave for full output swing. FIG. 5-3 below illustrates the test setup and the output waveform to be expected.



NOTE: 1) ENCLOSED NUMBERS ARE REAR BARRIER STRIP TERMINAL DESIGNATIONS.
2) COMPONENTS MARKED WITH "*" ON MODELS WITH SUFFIX "M" ONLY. ADD EXTERNALLY, IF APPLICATION REQUIRES.

a) TEST SETUP



b) OUTPUT WAVE FORM

FIG. 5-3 DYNAMIC MEASUREMENTS, BOP.

SECTION VI – ELECTRICAL PARTS LIST AND DIAGRAMS

6-1 GENERAL

6-2 This section contains the main schematic, the parts location diagrams, and a list of all replaceable electrical parts. All components are listed in alpha-numerical order of their reference designations. Consult your Kepco Representative for replacement of parts not listed here.

6-3 ORDERING INFORMATION

6-4 To order a replacement part or to inquire about parts not listed in the parts list, address order or inquiry either to your authorized Kepco Sales Representative or to:

KEPCO, INC.
131–38 Sanford Avenue
Flushing, N.Y. 11352

6-5 Specify the following information for each part:

a) Model and complete serial number of instrument.

b) Kepco part number.

c) Circuit reference designator.

d) Description.

6-6 To order a part not listed in the parts list, give a complete description and include its function and location.

AMPLIFIER ASSEMBLY (MASTER) (A1) MODEL BOP 72–5(M) Code 4-1770

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
C1	1	Capacitor,Ceramic,Disc. 47 pF, 1 K V, 20%	Sprague 5GA-Q47	117-0088
C2	1	Capacitor,Mica,Silver Dip 200 pF, 500V, 5%	Sangamo D155F201J0	117-0783
C3	1	Capacitor,Mica,Silver Dip 2200 pF, 500V, 5%	Sangamo D195F222J0	117-0784
C4	1	Capacitor,Mica,Silver Dip 100 pF, 500V, 5%	Sangamo D155F101J0	117-0673
C5	1	Capacitor,Mica,Silver Dip 150 pF, 500V, 5%	Cornell Dubilier CD15FD151JN3	117-0675
C7	1	Capacitor,Ceramic,Disc. 330 pF, 1 K V, 20%	Sprague 3C3015BH1	117-0556
C8	1	Capacitor,Ceramic,Disc. 100 pF, 2 K V, 10%	Radio Materials Type U	117-0056
CR1	1	Zener Diode,Pigtail	Transitron SV125	121-0028
CR2,3, 4,5,6,7	6	Zener Diode,Pigtail	International Resistance 1N821	121-0041
CR8,9,13	3	Rectifier,Silicon,Pigtail	Solitron 124-0178	124-0178
*CR10	1	Rectifier,Silicon,Bridge,Module	Varo EBR-W102	124-0346
Q1,8	2	Transistor,Silicon,NPN	RCA 2N3053	119-0059
Q3,7	2	Transistor,Silicon,PNP	RCA 2N4036	119-0074
Q4	1	Transistor,Silicon,NPN,Dual	Amelco 1502-122	119-0083
Q5,10	2	Transistor,Silicon,NPN	M.S. Transistor MST20	119-0079
Q6	1	Transistor,Silicon,NPN	RCA 2N2405	119-0086
Q9	1	Transistor,Silicon,PNP	Fairchild 2N4888	119-0085
R1	1	Resistor,Fixed,Precision,M.F. 182 ohm, 1 W, 1%	IRC CEC Type	115-2191
R2	1	Resistor,Fixed,M.G. 82 K ohm, 1/4 W, 5%	IRC RG 1/4	115-2012
R3	1	Resistor,Fixed,Molded 3.9 K ohm, 1/2 W, 5%	Allen Bradley EB3925	115-0808
R5,23	2	Resistor,Fixed,Power,Axial,WW 2 K ohm, 1 W, 3%	Tepro TS-1W	115-1524

*Models with suffix "M" only.

NOTE:
REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

AMPLIFIER ASSEMBLY (MASTER) (A1), MODEL BOP 72–5(M)

Code 5-770

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
R6,7,30	3	Resistor,Fixed,Precision,M.F. 301 ohm, 1 W, 1%	IRC CEC Type	115-2066
R8	1	Resistor,Fixed,Precision,M.F. 3.01 K ohm, 1/4 W, 1%	IRC CEA Type	115-2214
R9,13	2	Resistor,Fixed,Precision,M.F. 1 K ohm, 1/4 W, 1%	IRC CEA Type	115-2180
R10,11,12	3	Resistor,Fixed,Precision,WW 5.7 K ohm, 1 W, 1%	Tepro TS-1W	115-1301
R14	1	Resistor,Fixed,Precision,M.F. 3.01 K ohm, 1 W, 1%	IRC CES Type	115-1852
R15,17	2	Resistor,Fixed,Precision,M.F. 499 K ohm, 1/4 W, 1%	IRC CEA Type	115-2309
R16	1	Resistor,Fixed,Power,Axial,WW 2.5 K ohm, 1 W	Tepro TS-1W	115-1307
*R18	1	Resistor,Variable,Cermet 10 K ohm, 3/4 W, 20%	IRC 400-20	115-2345
*R19	1	Resistor,Fixed,Precision,M.F. 60.4 K ohm, 1 W, 1%	IRC CES Type	115-1815
R20	1	Resistor,Fixed,Power,Axial 10 K ohm, 5 W, 3%	Tepro TS-5W	115-1635
R21,34,36	3	Resistor,Fixed,Molded 100 ohm, 1/4 W, 10%	IRC GBT 1/4	115-2231
R22	1	Resistor,Fixed,Power,Axial,WW 25 ohm, 3 W, 5%	Tepro TS-3C	115-0779
R24	1	Resistor,Fixed,Power,Axial,WW 8 K ohm, 5 W, 3%	Tepro TS-5W	115-1652
R25	1	Resistor,Fixed,Precision,M.F. 511 ohm, 1/4 W, 1%	IRC CEA Type	115-2260
R26	1	Resistor,Fixed,Power,Axial,WW 15 K ohm, 1 W, 3%	Tepro TS-1W	115-1414
R27,28	2	Resistor,Fixed,Molded 5.1 K ohm, 1/2 W, 5%	Allen Bradley EB5135	115-1659
R31	1	Resistor,Fixed,Molded 6.2 K ohm, 1/2 W, 5%	Allen Bradley EB6235	115-0744
R35,37	2	Resistor,Variable,Cermet 10 ohm, 3/4 W, 30%	Helipot 78PR10	115-2062
R38	1	Resistor,Fixed,Molded 10 ohm, 1/4 W, 10%	IRC GBT 1/4	115-2230
S1	1	Switch,Slide,SPST	Stackpole SS-26	127-0216

*Models with suffix "M" only.

NOTE:
REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND S LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

REPLACEMENT PARTS LIST

MAIN CHASSIS ASSEMBLY (A2), MODEL BOP 72–5(M) **Code 5-770**

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
FRONT PANEL ASSEMBLY:				
CB101	1	Circuit Breaker	Heinemann JA2-A5A5	127-0277
DS101	1	Pilot Light Assembly	Industrial Devices Type IV	152-0089
*M101	1	Meter,Volt 0–75V	Ammon Type FM-2	135-0468
*M102	1	Meter,Amp. 0–5A	Ammon Type FM-2	135-0470
*R101	1	Resistor,Variable,WW 1 K ohm, 3 W, 3%	IRC Type 8000	115-1304
*R102	1	Resistor,Variable,WW 40 K ohm, 3 W, 3%	Fluke 24A-5044	115-2366
*S101	1	Switch,Slide,SPST	Stackpole SS-47	127-0278
*S102	1	Switch,Slide,3PDT	UID Electronics Type SW332	127-0282
MISCELLANEOUS PARTS:				
	1	Barrier-Strip, 11 Terminal		167-0627
	4	Binding Post, Black*		151-0026
	1	Binding Post, Blue*		151-0027
	1	Binding Post, Green*		151-0048
	1	Binding Post, Red*		151-0025
TB1301	1	Binding Post, White*		151-0029
	1	Binding Post, Yellow*		151-0055
	1	Control Knob, Large*		155-0046
	1	Control Knob, Locking Type*		155-0047
	1	Control Knob, Small*		155-0048
	2	Fan Blade		149-0023
	1	Handle Assembly*		139-0197
	1	Heat Sink for TO-5 Case		136-0131
	1	Line Cord*		118-0506

*Used on models with suffix "M" only.

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

PLEASE NOTE: THE MANUFACTURER'S NAME AND PART NUMBER LISTED FOR EACH ITEM ON REPLACEMENT PARTS LISTS, REPRESENTS AT LEAST ONE SOURCE FOR THAT ITEM AND IS LISTED SOLELY FOR THE CONVENIENCE OF KEPCO EQUIPMENT OWNERS IN OBTAINING REPLACEMENT PARTS LOCALLY. WE RESERVE THE RIGHT TO USE EQUIVALENT ITEMS FROM ALTERNATE SOURCES. KEPCO, INC.

MAIN CHASSIS ASSEMBLY (A2), MODEL BOP 72–5(M) Code 4-1770

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
B201,202	2	Fan,Motor	Howard Industries 23112	148-0027
C201,202, 203,204,205, 206,207,208	8	Capacitor,Electrolytic,Can 5900 μF, 75V	General Electric 86F500-MI Series	117-0738
C209,210, 211,212,213 214,215,216	8	Capacitor,Mylar,Pigtail 0.02 μF, 200V, 10%	Sprague 192P20392	117-0377
CR201,202, 203,204,205, 206,207,208	8	Rectifier,Silicon,Pigtail	Semicon S-5A4	124-0348
K201,202	2	Relay	Line Electric MK1027	140-0018
L201,202, 203,204	4	Choke	Kepco Magnetics 100-1890	100-1890
R201	1	Resistor,Fixed,Power,Strip 200 ohm, 20 W, 5%	Hardwick Hindle 2BRS-53B-200	115-0570
R202,207	2	Resistor,Fixed,Power,Strip 3 ohm, 20 W, 5%	Hardwick Hindle 2BRS-56-3	115-0726
R203,204, 205,206	4	Resistor,Fixed,Power,Axial 10 K ohm, 3 W, 5%	Tepro TS-3C	115-0460
R208	1	Resistor,Fixed,Power,Strip 0.1 ohm, 20 W, 5%	Memcor Type 2BRS-53B	115-0696
T201	1	Transformer	Kepco Magnetics 100-1817	100-1817
T202	1	Transformer	Kepco Magnetics 100-1880	100-1880
T203	1	Transformer	Kepco Magnetics 100-1881	100-1881

NOTE:

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AUXILIARY ASSEMBLY (MASTER) (A3), MODEL BOP 72–5(M) Code 4-1770

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
C301	1	Capacitor,Electrolytic,Pigtail 68 μF, 50V, 20%	General Electric 76F02LN680	117-0511
C302,303	2	Capacitor,Electrolytic,Pigtail 400 μF, 75V	General Electric 43F7573AA1	117-0432
C304	1	Capacitor,Mylar,Pigtail 1 μF, 200V, 10%	Wesco 33MM	117-0395
C305	1	Capacitor,Ceramic,Disc. 100 pF, 2 K V, 10%	Radio Materials Type U	117-0056
C306	1	Capacitor,Electrolytic,Pigtail 10 μF, 6V	Sprague 30D106G006BA2	117-0678
C307	1	Capacitor,Electrolytic,Pigtail 200 μF, 100V	Clarostat 43C2-50K	117-0598
CR301,306	2	Rectifier,Silicon,Bridge	Varo EBR-W102	124-0346
CR302,303, 304,305,308	5	Rectifier,Silicon,Pigtail	Semtech SE-4	124-0028
CR307	1	Rectifier,Silicon,Pigtail	Solitron 124-0178	124-0178
Q301	1	Transistor,Silicon,NPN	Fairchild 2N3569	119-0092
Q302	1	Transistor,Silicon,NPN	General Electric 2N336A	119-0056
Q303	1	Transistor,Silicon,NPN	M.S. Transistor MST20	119-0079
R301,302	2	Resistor,Fixed,Molded 68 K ohm, 1/2 W, 5%	Allen Bradley EB6835	115-0856
R303	1	Resistor,Fixed,Precision,M.F. 20 K ohm, 1 W, 1%	IRC CEC Type	115-2039
R304	1	Resistor,Fixed,Molded 1 K ohm, 1/2 W, 10%	Allen Bradley EB1021	115-0547
R305	1	Resistor,Fixed,Precision,M.F. 1 K ohm, 1 W, 1%	IRC CES Type	115-1822
R306,308	2	Resistor,Fixed,Power,Axial,WW 10 K ohm, 5 W, 3%	Tepro TS-5W	115-1635
R307	1	Resistor,Fixed,Power,Axial,WW 5 K ohm, 5 W, 5%	Tepro TS-5W	115-0232
R309	1	Resistor,Fixed,Power,Axial,WW 2 K ohm, 5 W, 5%	Tepro TS-5W	115-0568

NOTE:
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DRIVER AND PASS ASSEMBLIES (MASTER), MODEL BOP 72–5(M)

Code 5-770

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
DRIVER ASSEMBLY (MASTER) (A4):				
C401	1	Capacitor,Mica,Silver Dip 200 pF, 6 K V	Centralab DD60-201	117-0075
Q401,402,403	3	Transistor,Silicon,NPN	RCA 2N3442	119-0070
R401	1	Resistor,Fixed,Power,Axial 7.5 ohm, 3 W, 5%	Tepro TS-3C	115-0823
R402	1	Resistor,Fixed,Molded 4.7 ohm, 1 W, 10%	Allen Bradley GB4721	115-0434
R403	1	Resistor,Fixed,Power,Axial,WW 30 ohm, 3 W, 5%	Tepro TS-3C	115-0773
PASS ASSEMBLY (MASTER) (A5):				
CR501,502,503	3	Rectifier,Silicon,Pigtail	Semtech SE-4	124-0028
Q501,502,503 504,505,506	6	Transistor,Silicon,NPN	RCA 2N3773	119-0091
Q507,508,509 510,511,512	6	Transistor,Silicon,PNP	Motorola 2N4399	119-0090
R501,502,503 504,505,506	6	Resistor,Fixed,WW 0.5 ohm, 3 W, 3%	Tepro TS-3WNI	115-1880
R507,508,509 510,511,512	6	Resistor,Fixed,WW 0.333 ohm, 3 W, 3%	Tepro TS-3CNI	115-2305
S501	1	Switch,Thermostat	Stemco 110486	127-0248

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

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AMPLIFIER ASSEMBLY (SLAVE) (A6), MODEL BOP 72–5(M) Code 4-1770

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
C601,602	2	Capacitor,Mica,Silver Dip 150 pF, 500V, 5%	Cornell Dubilier CD15FD151J03	117-0675
C603	1	Capacitor,Ceramic,Disc. 100 pF, 2 K V, 10%	Radio Materials Type U	117-0056
C604	1	Capacitor,Mica,Silver Dip 100 pF, 500V, 5%	Cornell Dubilier CD15FD101J03	117-0673
CR601,603,604	3	Zener Diode,Pigtail	Transitron 1N763-1	121-0028
CR602	1	Zener Diode,Pigtail	International Rectifier 1N1773	121-0012
CR605,606	2	Rectifier,Silicon,Pigtail	EDI CEC1000	124-0178
Q601	1	Transistor,Silicon,NPN	RCA 2N3053	119-0059
Q602	1	Transistor,Silicon,NPN	Amelco 1502-122	119-0083
Q603	1	Transistor,Silicon,PNP	RCA TA2651	119-0074
Q604	1	Transistor,Silicon,NPN	RCA 2N2405	119-0086
Q605	1	Transistor,Silicon,NPN	M.S. Transistor MST-20	119-0079
R601	1	Resistor,Fixed,Precision,M.F. 475 ohm, 1 W, 1%	IRC CES Type	115-1935
R602	1	Resistor,Fixed,M.G. 82 K ohm, 1/4 W, 5%	IRC RG-1/4	115-2012
R603	1	Resistor,Fixed,Molded 3.9 K ohm, 1/2 W, 5%	Allen Bradley EB3925	115-0808
R604	1	Resistor,Fixed,Precision,M.F. 3.92 K ohm, 1/4 W, 1%	IRC CEA Type	115-2179
R606,607,608	3	Resistor,Fixed,Precision,WW 5.7 K ohm, 1 W, 1%	Tepro TS-1W	115-1301
R609	1	Resistor,Fixed,Precision,M.F. 1 K ohm, 1/4 W, 1%	IRC CEA Type	115-2180
R610	1	Resistor,Fixed,Precision,M.F. 3.01 K ohm, 1 W, 1%	IRC CES Type	115-1852
R611,612	2	Resistor,Fixed,Power,Axial 4 K ohm, 5 W, 5%	Tepro TS-5W	115-0753
R613	1	Resistor,Fixed,Molded 100 ohm, 1/2 W, 5%	Allen Bradley EB1015	115-0341

NOTE:

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AUXILIARY ASSEMBLY (SLAVE) (A6), MODEL BOP 72–5(M) Code 4-1770

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
R614	1	Resistor,Fixed,Molded 10 ohm, 1/2 W, 10%	Allen Bradley EB1001	115-0502
R615,618	2	Resistor,Fixed,Molded 5.1 K ohm, 1/2 W, 5%	Allen Bradley EB5125	115-1659
R616	1	Resistor,Fixed,Power,Axial,WW 15 K ohm, 1 W, 3%	Tepro TS-1W	115-1414
R617	1	Resistor,Fixed,Precision 510 ohm, 1 W, 1%	Tepro TS-5W	115-1466
R619,621	2	Resistor,Fixed,Power,Axial 10 K ohm, 5 W, 3%	Tepro TS-5W	115-1635
R620	1	Resistor,Fixed,Power,Axial,WW 25 ohm, 3 W, 5%	Tepro TS-3C	115-0779

NOTE:
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AUXILIARY ASSEMBLY (SLAVE) (A7), MODEL BOP 72–5(M)

Code 4-1770

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
C701	1	Capacitor,Electrolytic,Pigtail 68 μF, 50V	General Electric 76F02LN680	117-0511
C702,703	2	Capacitor,Electrolytic,Pigtail 400 μF, 75V	General Electric 43F7573AA1	117-0432
C704	1	Capacitor,Mylar,Pigtail 1 μF, 200V, 10%	Wesco 33MM	117-0395
C705	1	Capacitor,Ceramic,Disc. 100 pF, 2 K V, 10%	Radio Materials Type U	117-0056
C707	1	Capacitor,Electrolytic,Pigtail 200 μF, 100V	General Electric 43F9347AA1	117-0598
CR701,706	2	Rectifier,Silicon,Bridge	Varo EBR-W102	124-0346
CR702,703, 704,705,708	5	Rectifier,Silicon,Pigtail	Semtech SE-4	124-0028
CR707	1	Rectifier,Silicon,Pigtail	EDI CEC1000	124-0178
Q701	1	Transistor,Silicon,NPN	Fairchild 2N3569	119-0092
Q703	1	Transistor,Silicon,NPN	M.S. Transistor MST-20	119-0079
R701,702	2	Resistor,Fixed,Molded 68 K ohm, 1/2 W, 5%	Allen Bradley EB6825	115-0856
R703	1	Resistor,Fixed,Precision,M.F. 20 K ohm, 1 W, 1%	IRC CEC Type	115-2039
R705	1	Resistor,Fixed,Precision,M.F. 1 K ohm, 1 W, 1%	IRC CES Type	115-1822
R706,708	2	Resistor,Fixed,Power,Axial,WW 10 K ohm, 5 W, 3%	Tepro TS-5W	115-1635
R707	1	Resistor,Fixed,Power,Axial,WW 5 K ohm, 5 W, 5%	Tepro TS-5W	115-0232
R709	1	Resistor,Fixed,Power,Axial,WW 2 K ohm, 5 W, 5%	Tepro TS-5W	115-0568

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

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DRIVER AND PASS ASSEMBLIES (SLAVE), MODEL BOP 72–5(M)

Code 5-770

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
DRIVER ASSEMBLY (SLAVE) (A8):				
C801	1	Capacitor,Ceramic,Disc. 200 pF, 6 K V	Ohmite Type 625	117-0075
Q801,802,803	3	Transistor,Silicon,NPN	RCA 2N3442	119-0070
R801	1	Resistor,Fixed,Power,Axial 7.5 ohm, 3 W, 5%	Tepro TS-3C	115-0823
R802	1	Resistor,Fixed,Molded 4.7 ohm, 1 W, 10%	Allen Bradley GB4701	115-0434
R803	1	Resistor,Fixed,Power,Axial,WW 30 ohm, 3 W, 5%	Tepro TS-3C	115-0773
PASS ASSEMBLY (SLAVE) (A9):				
CR901,902,903	3	Rectifier,Silicon,Pigtail	Semtech SE-4	124-0028
Q901,902,903, 904,905,906	6	Transistor,Silicon,NPN	RCA 2N3773	119-0091
Q907,908,909, 910,911,912	6	Transistor,Silicon,PNP	Motorola 2N4399	119-0090
R901,902,903, 904,905,906	6	Resistor,Fixed,WW 0.5 ohm, 3 W, 3%	Tepro TS-3WNI	115-1880
R907,908,909, 910,911,912	6	Resistor,Fixed,WW 0.333 ohm, 3 W, 3%	Tepro TS-3CNI	115-2305
S901	1	Switch,Thermostat	Stemco 110486	127-0248

NOTE:

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CHASSIS SUBASSEMBLIES, MODEL BOP 72–5(M) Code 4-1770

SCHEMATIC NO.	QTY.	DESCRIPTION	MFRS. NAME & PART NO. (SEE NOTE)	KEPCO PART NO.
OFFSET ADJUSTMENT ASSEMBLY (A10):				
C1001	1	Capacitor,Mylar,Pigtail 0.1 μF, 600V	TRW X663F	117-0316
C1002,1003	2	Capacitor,Electrolytic,Pigtail 150 μF, 3V	Sangamo Type 052	117-0757
R1001,1002	2	Resistor,Variable,WW 20 K ohm, 1 W, 5%	IRC Type 400-20	115-2363
R1003	1	Resistor,Fixed,Molded 10 ohm, 1/2 W, 5%	Allen Bradley EB1005	115-0502
R1004	1	Resistor,Fixed,WW 4 K ohm, 1 W, 5%	Tepro TS-1W	115-1637
*R1005	1	Resistor,Fixed,Power,Axial 1 K ohm, 3 W, 5%	Tepro TS-3C	115-1302
RESISTOR BOARD (MASTER) (A11):				
R1101,1104	2	Resistor,Fixed,Power,Axial 0.15 ohm, 10 W, 5%	Tepro TS-10W	115-1795
R1102,1103	2	Resistor,Fixed,Power,Axial 0.083 ohm, 10 W, 5%	Tepro TS-10C	115-1717
RESISTOR BOARD (SLAVE) (A12):				
CR1201,1202	2	Rectifier,Silicon,Controlled	Motorola 2N4442	124-0350
R1201,1202	2	Resistor,Fixed,Power,Axial 0.25 ohm, 10 W, 5%	Tepro TS-10W	115-1705
TERMINAL ASSEMBLY (BARRIER-STRIP) (A13):				
*R1301	1	Resistor,Fixed,Molded 39 K ohm, 1/2 W, 10%	Allen Bradley EB3921	115-1137

*Not used in "M" version.

NOTE:

REPLACEMENT PARTS MAY BE ORDERED FROM KEPCO, INC. ORDERS SHOULD INCLUDE KEPCO PART NUMBER AND DESCRIPTION.

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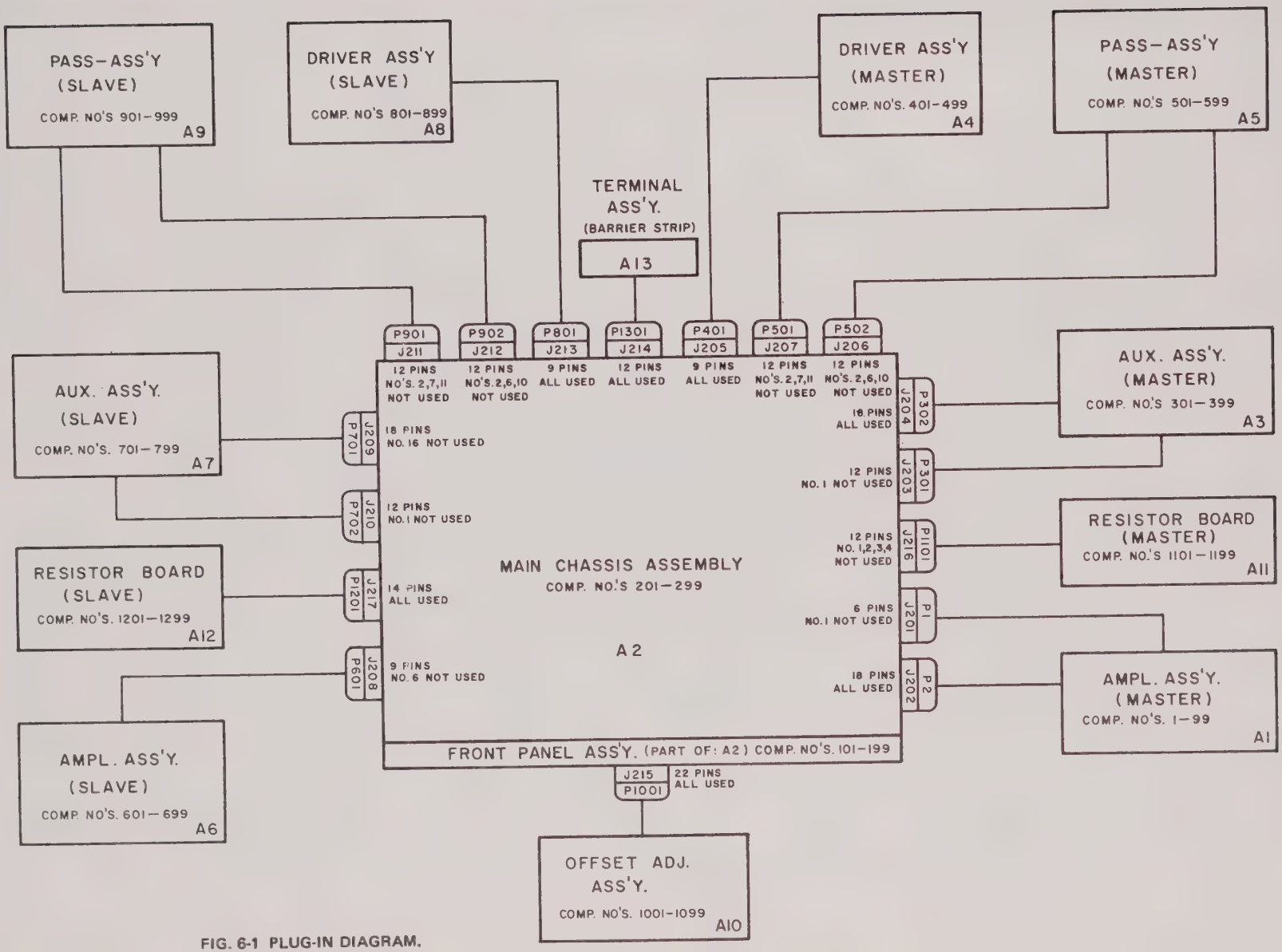


FIG. 6-1 PLUG-IN DIAGRAM.

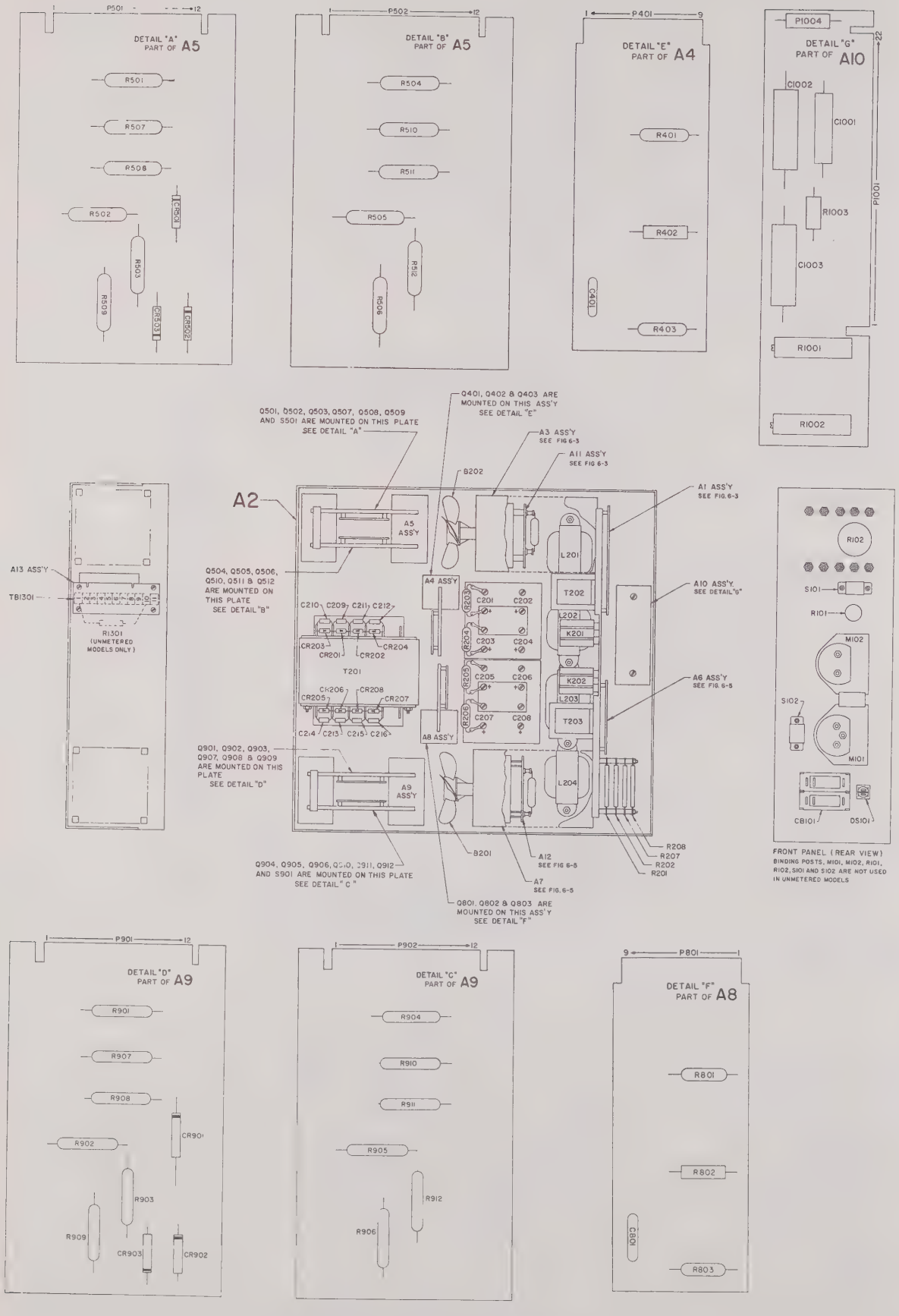
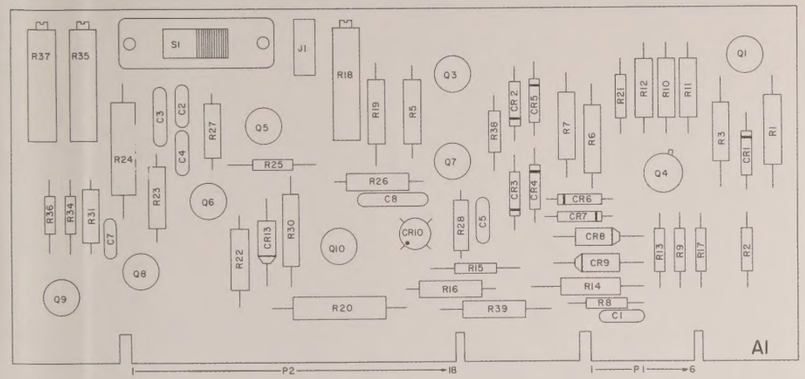
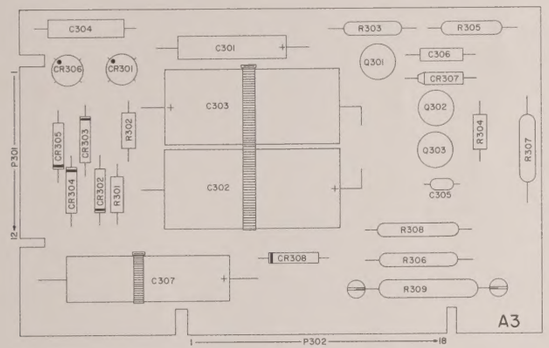


FIG. 6-2 COMPONENT LOCATION, MAIN CHASSIS, OFFSET ADJ. AND HEAT SINK ASSEMBLIES.





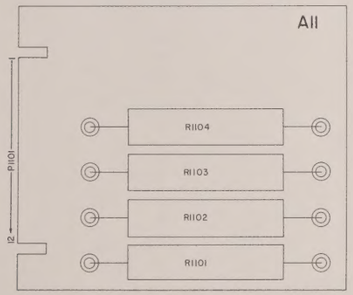
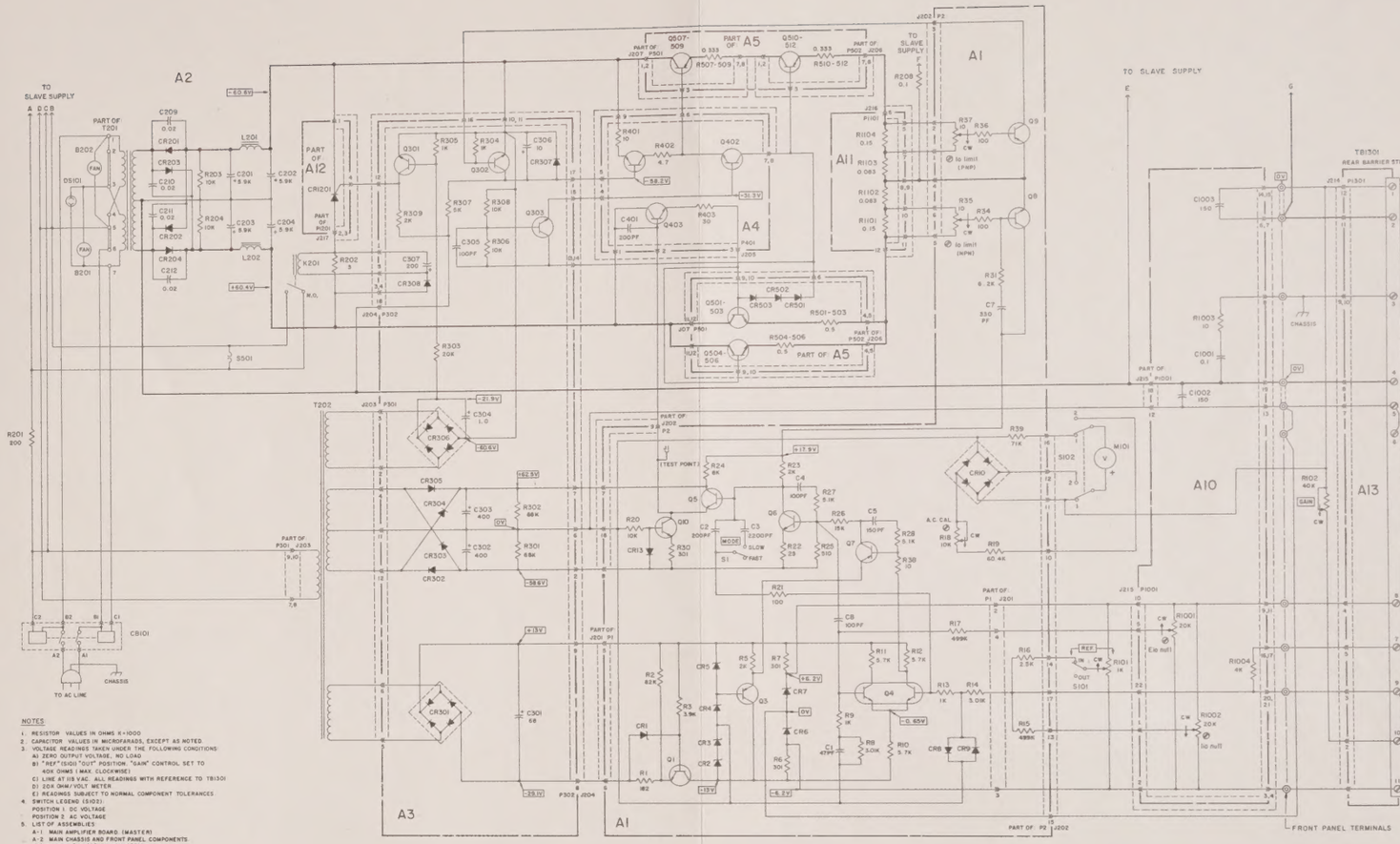


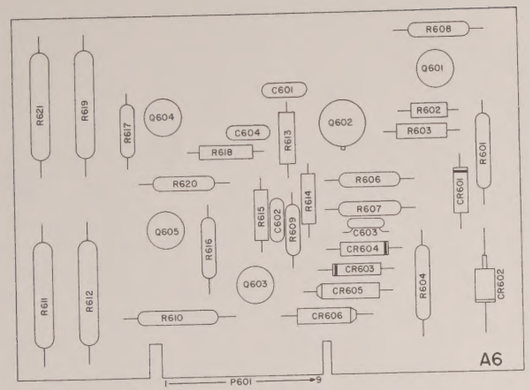
FIG. 6-3 COMPONENT LOCATION, ASSEMBLIES A1, A3 and A11
(MASTER SECTION)

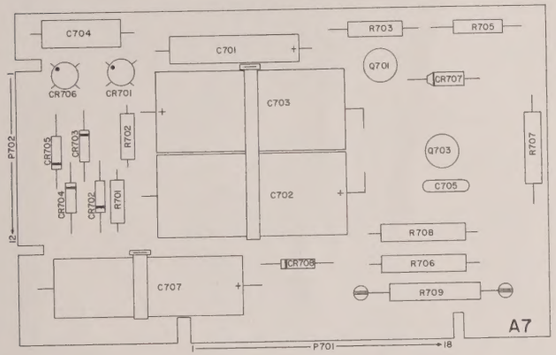


NOTES
1. RESISTOR VALUES IN OHMS K=1000
2. CAPACITOR VALUES IN MICROFARADS, EXCEPT AS NOTED
3. VOLTAGE READINGS TAKEN UNDER THE FOLLOWING CONDITIONS:
   A) ZERO OUTPUT VOLTAGE, NO LOAD
   B) "REF"(S101) "OUT" POSITION. "GAIN" CONTROL SET TO 40K OHMS (MAX. CLOCKWISE)
   C) LINE AT 115 VAC. ALL READINGS WITH REFERENCE TO TB1301
   D) 20K OHM/VOLT METER
   E) READINGS SUBJECT TO NORMAL COMPONENT TOLERANCES
4. SWITCH LEGEND (S102):
   POSITION 1. DC VOLTAGE
   POSITION 2. AC VOLTAGE
5. LIST OF ASSEMBLIES:
   A-1 MAIN AMPLIFIER BOARD (MASTER)
   A-2 MAIN CHASSIS AND FRONT PANEL COMPONENTS
   A-3 AUXILIARY ASSEMBLY (MASTER)
   A-4 DRIVER ASSEMBLY (MASTER)
   A-5 PASS-ASSEMBLY (MASTER)
   A-6 MAIN AMPLIFIER BOARD (SLAVE)
   A-7 AUXILIARY ASSEMBLY (SLAVE)
   A-8 DRIVER ASSEMBLY (SLAVE)
   A-9 PASS-ASSEMBLY (SLAVE)
   A-10 OFFSET ADJUSTMENT ASS'Y.
   A-11 RESISTOR BOARD ASS'Y. (MASTER)
   A-12 RESISTOR BOARD ASS'Y. (SLAVE)
   A-13 OUTPUT TERMINAL ASS'Y.
6. SEE PLUG-IN DIAGRAM FOR LIST OF CONNECTORS AND UNUSED PIN NUMBERS.

FIG. 6-4 MAIN SCHEMATIC, MODEL BOP 72-5M
(PART I, MASTER SECTION)

kepco Data subject to change without notice.
PATENT NOTICE: Applicable Patent Nos. ® will be supplied on request.





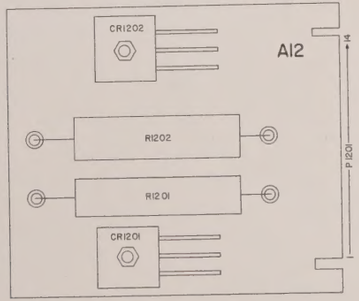
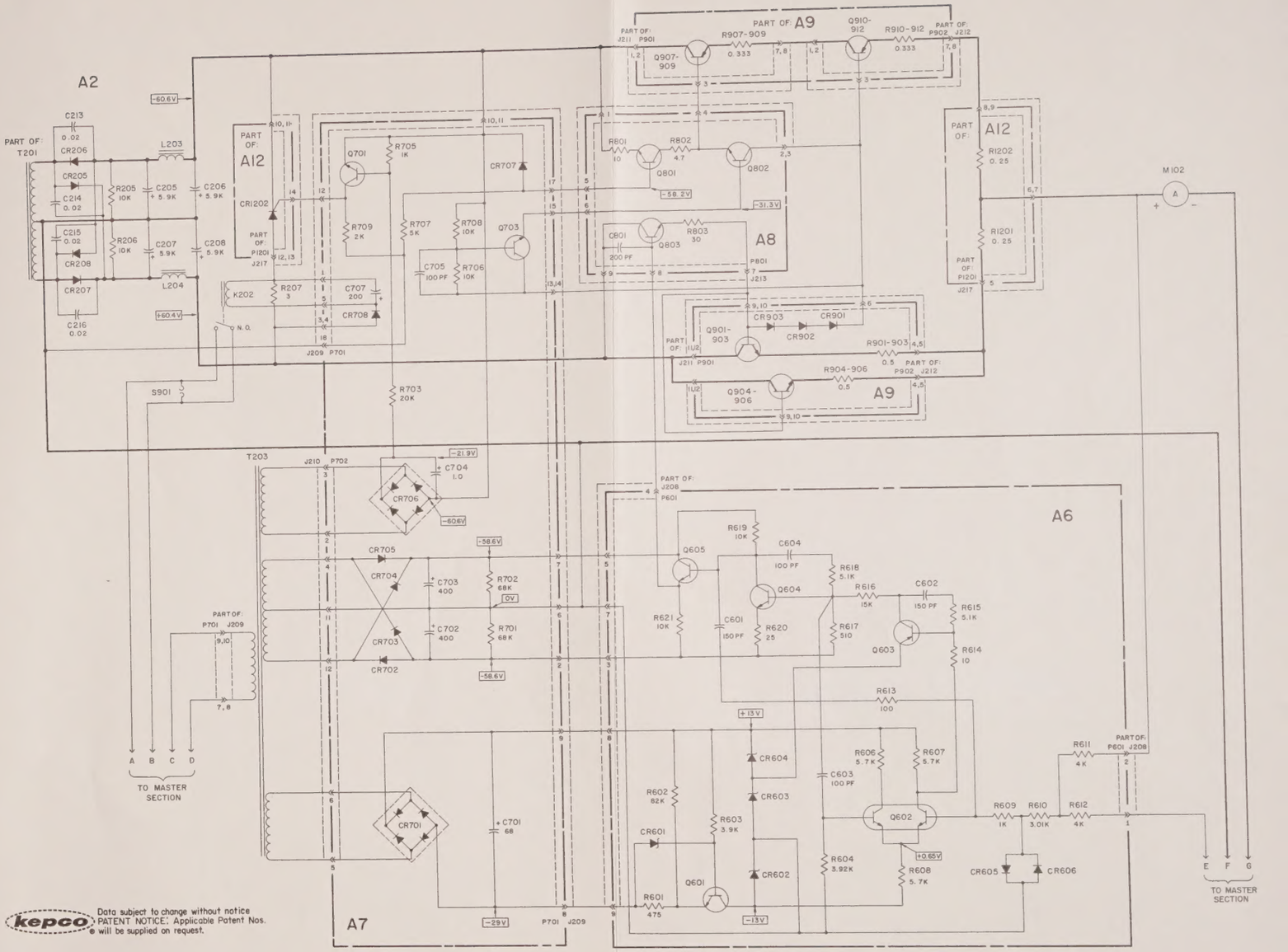


FIG. 6-5 COMPONENT LOCATION, ASSEMBLIES A6, A7 and A12 (SLAVE SECTION)



kepco Data subject to change without notice. PATENT NOTICE: Applicable Patent Nos. will be supplied on request.

FIG. 6-6 MAIN SCHEMATIC, MODEL BOP 72-5M (PART II, SLAVE SECTION)

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